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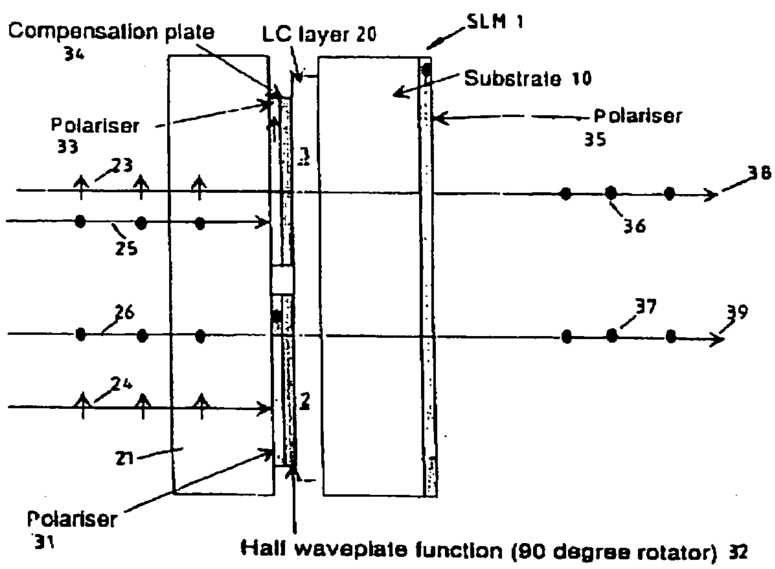
(54) **Spatial light modulator**

(57) A spatial light modulator which may be used in 3D displays of stereoscopic or autostereoscopic type comprises substrates (10, 21) between which is disposed a liquid crystal layer (20). The layer comprises two sets of pixels (2, 3) for displaying left and right eye images. A pixellated polarisation adjustor (31, 32; 33, 34) is disposed between one of the substrates (21) and the liquid crystal layer (20) so as to minimise parallax effects. The pixels (2, 3) of the liquid crystal layer (20) are operated in the same mode i.e. all normally black or all normally white.

Figure 5



GB 2 296 099 A

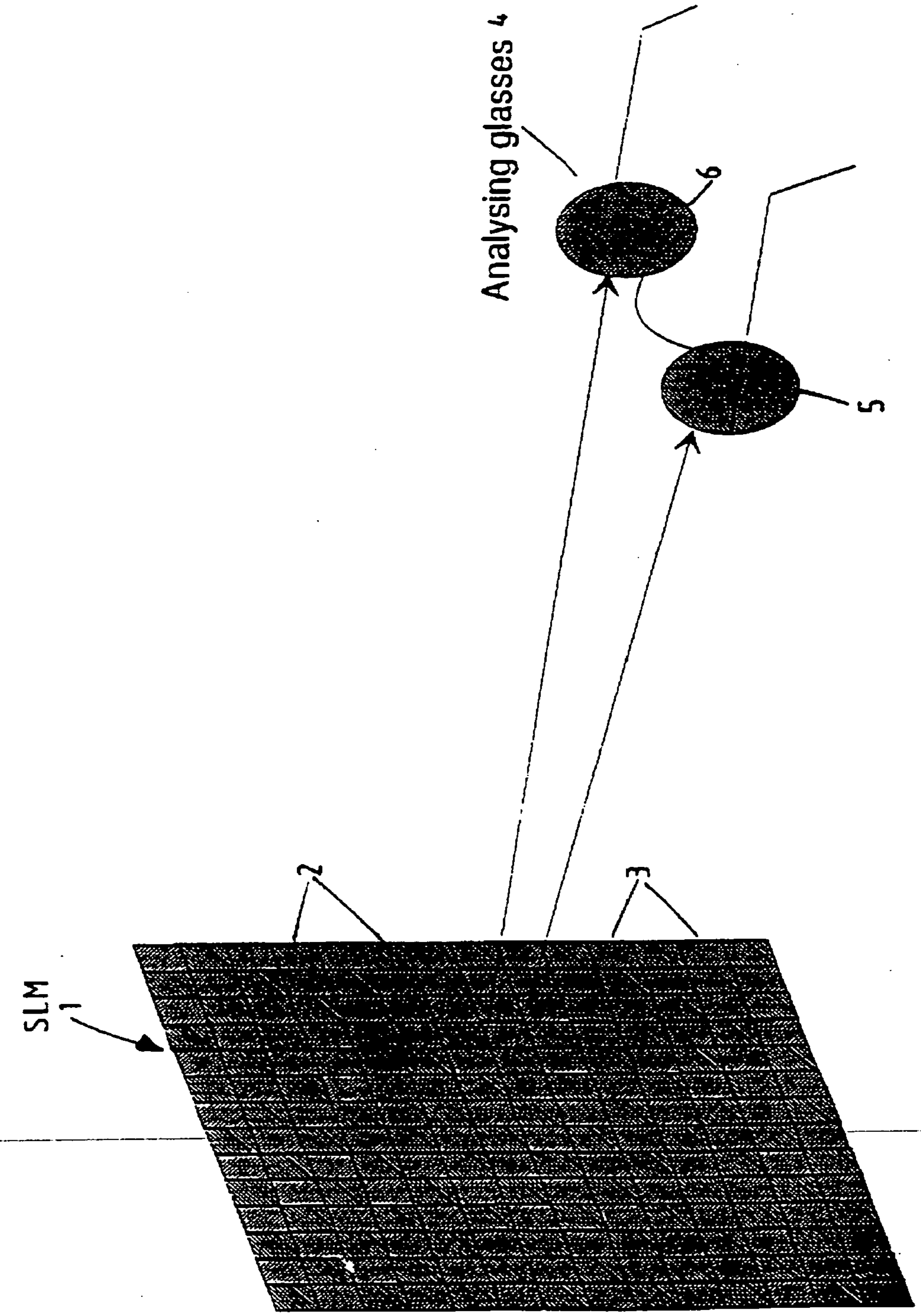


Figure 1

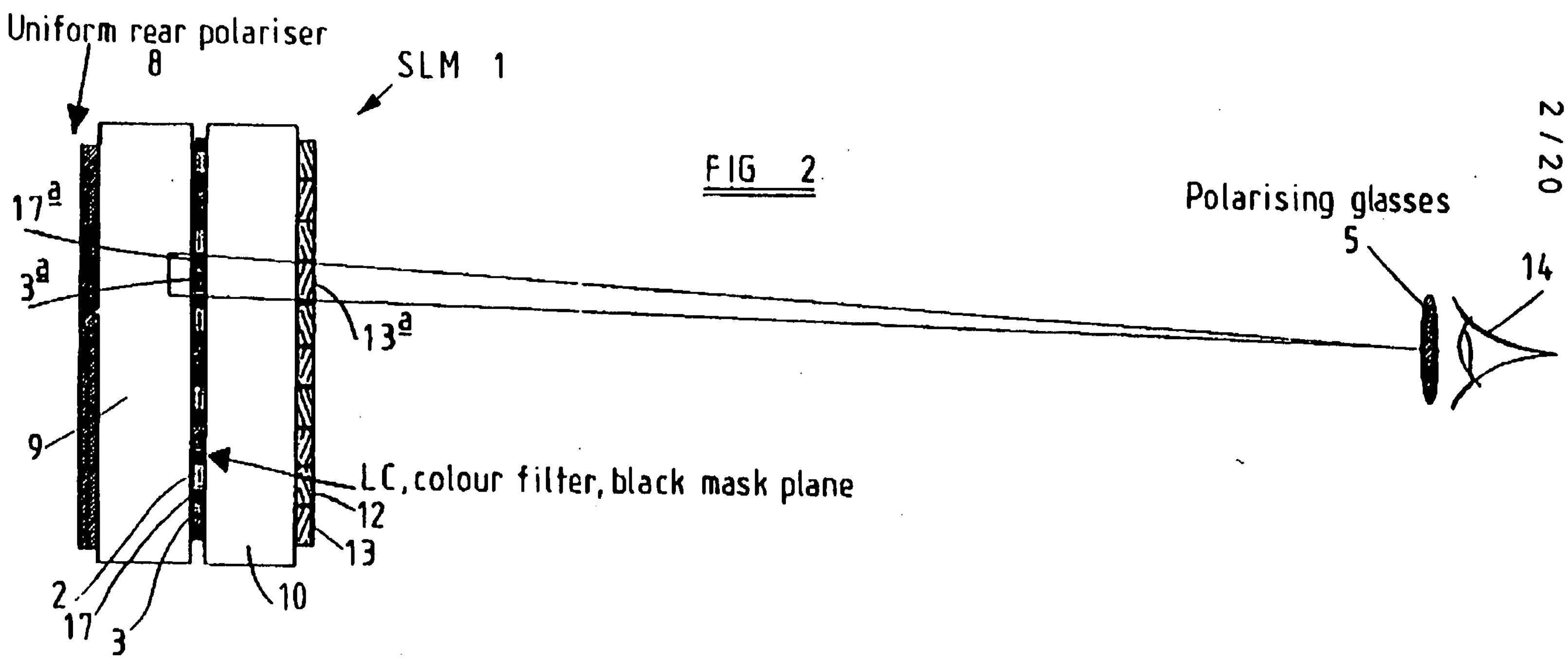
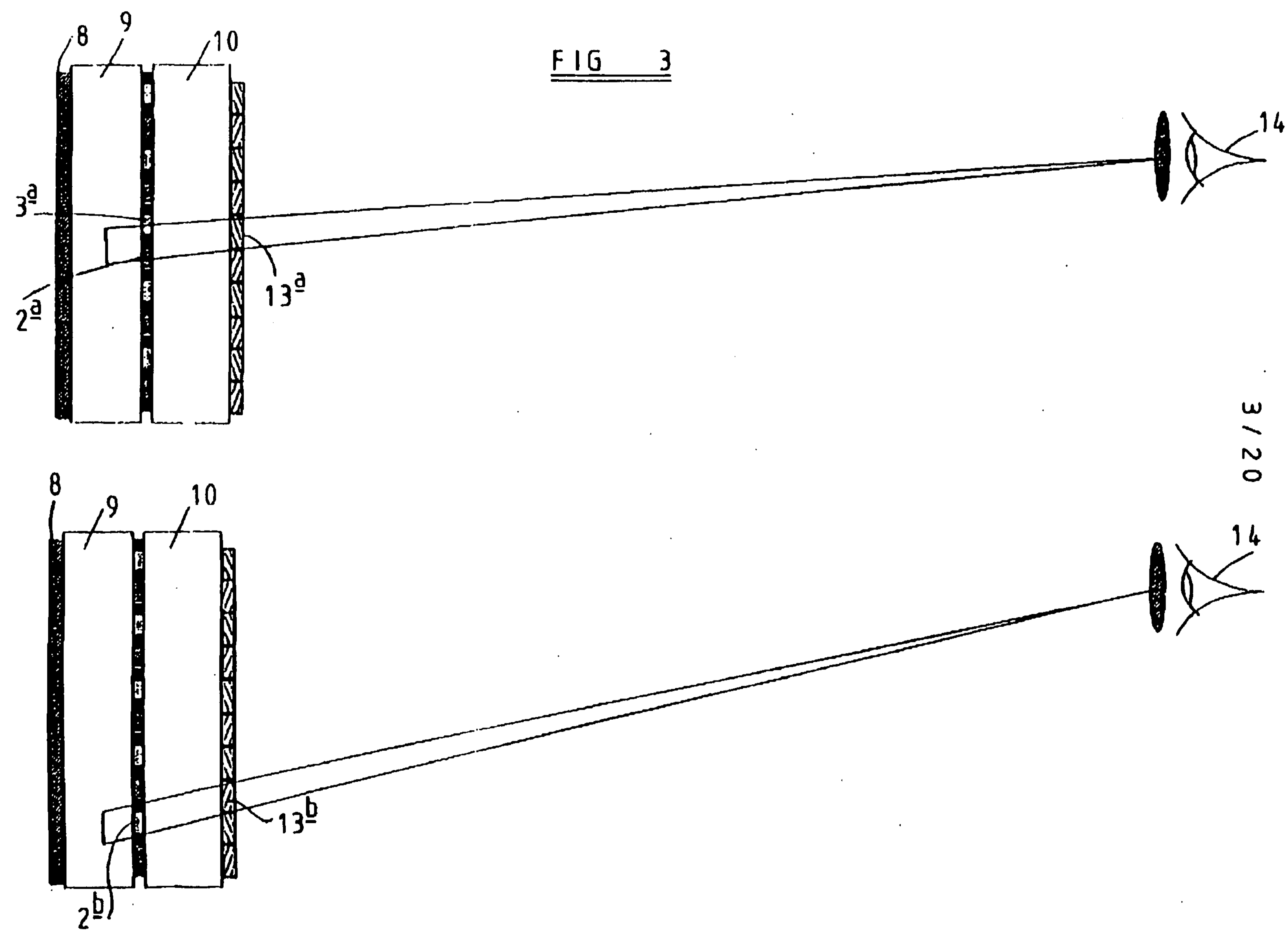

Uniform rear polariser
8
SLM 1
17a
3a
13a
9
LC, colour filter, black mask plane
12
13
2
17
3
10
Polarising glasses
5
14

FIG 2

FIG 3



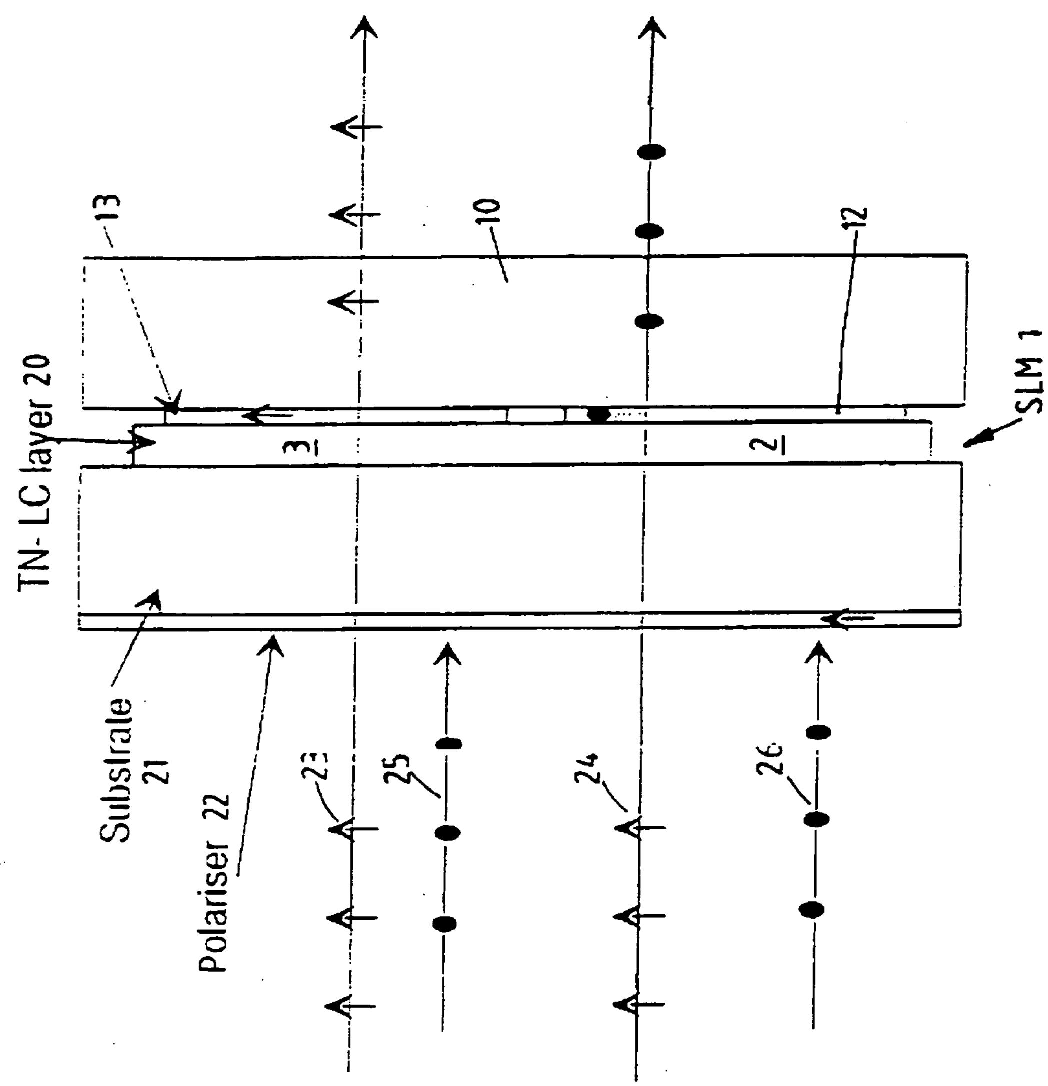
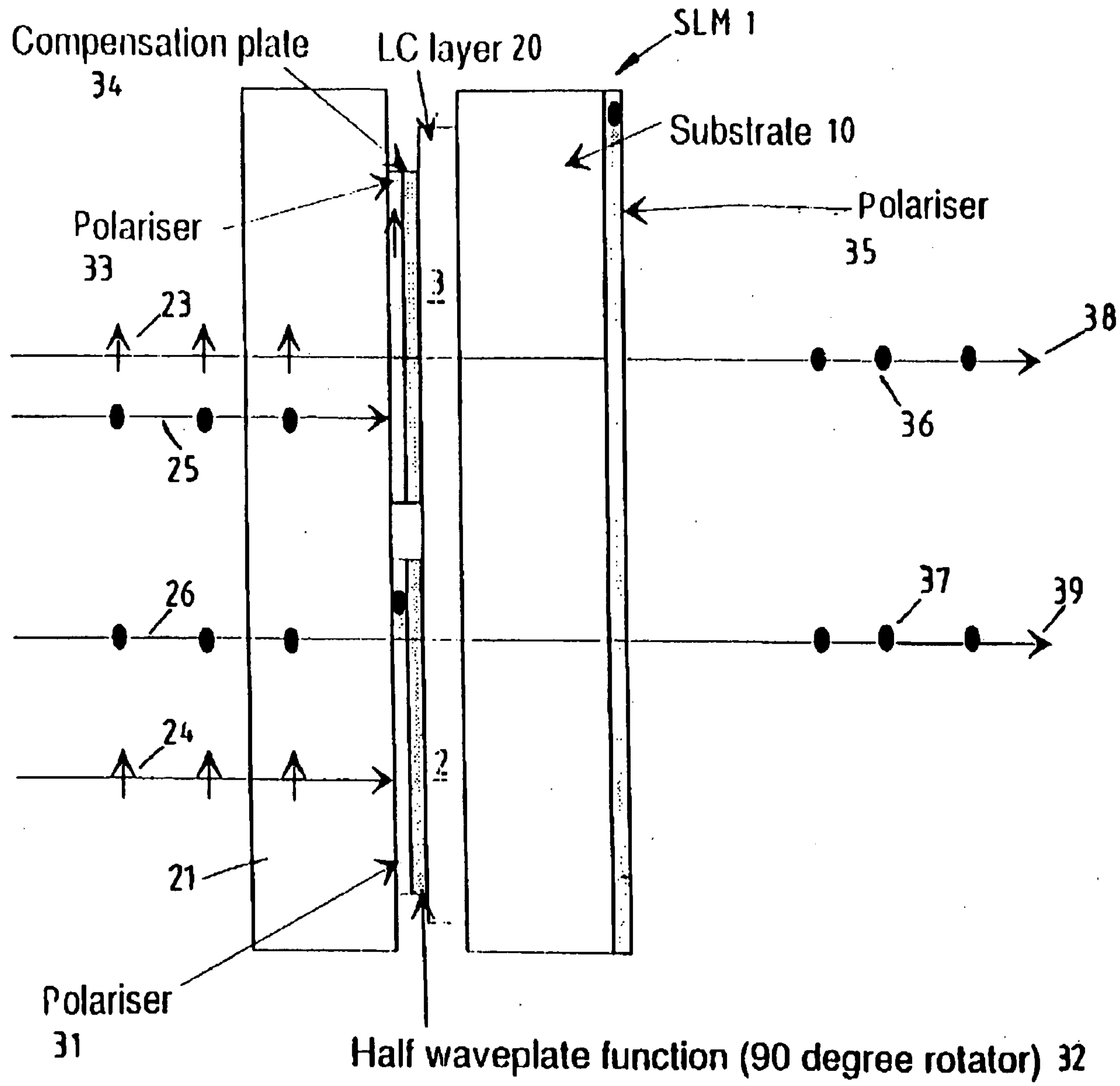
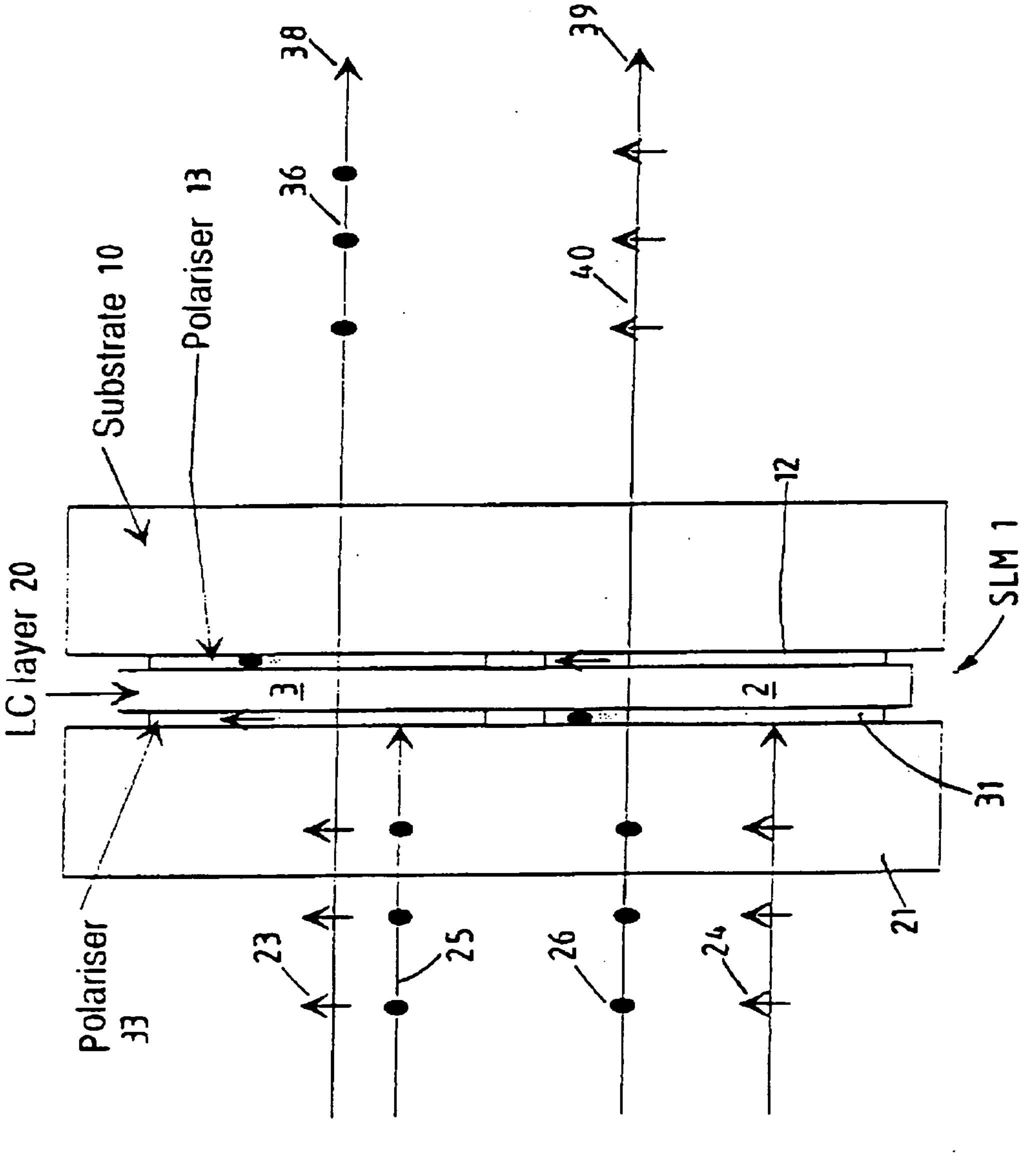

TN- LC layer 20
13
10
12
SLM 1
3
2
Substrate 21
Polariser 22
23
25
24
26

Figure 4

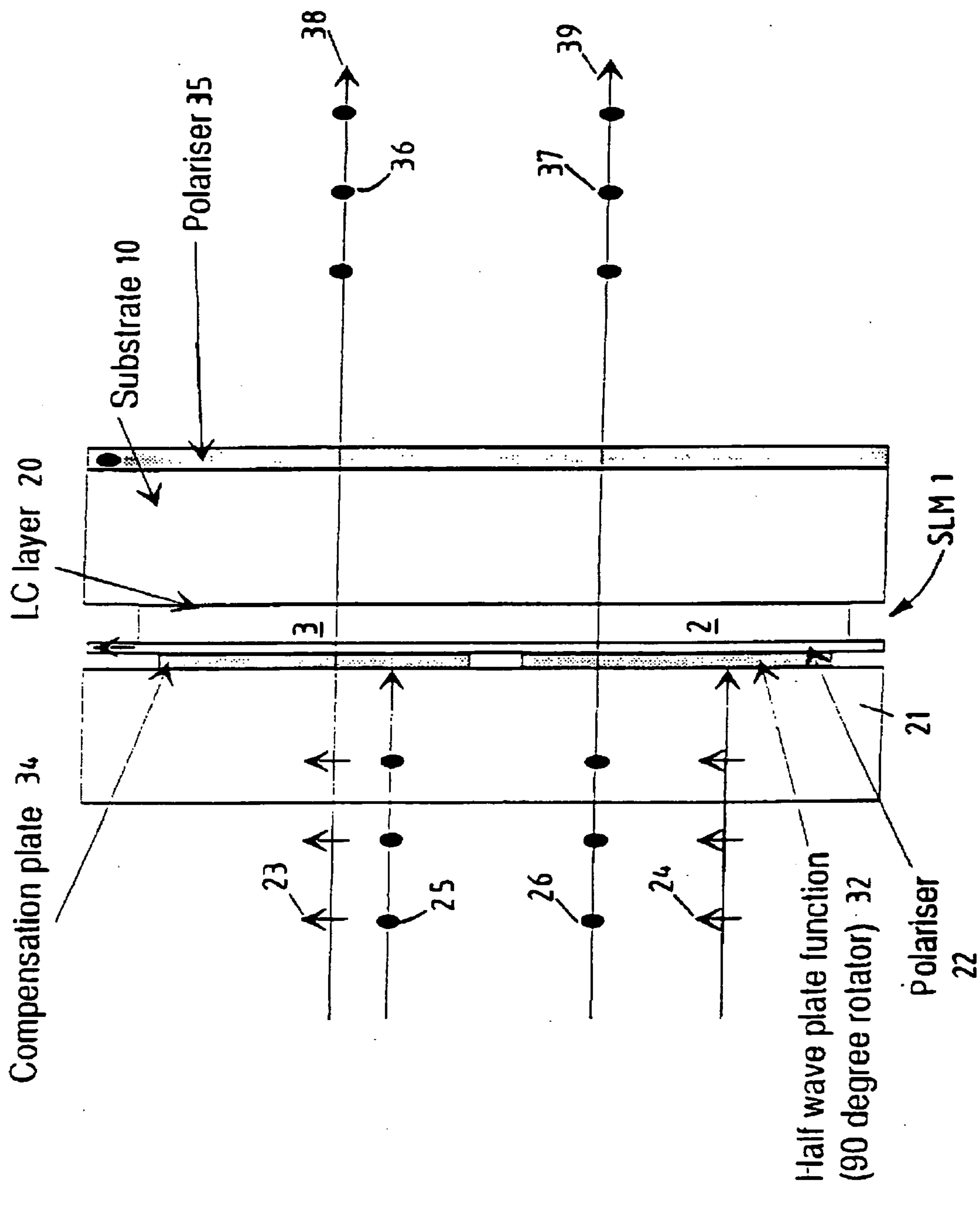
Figure 5


Compensation plate
34
LC layer 20
SLM 1
Substrate 10
Polariser
33
Polariser
35
23
38
25
36
3
26
37
39
24
2
21
Polariser
31
Half waveplate function (90 degree rotator) 32



38
39
36
40
Substrate 10
Polariser 13
12
LC layer 20
3
2
SLM 1
31
Polariser 33
23
25
26
24
21

Figure 6



Compensation plate 34
LC layer 20
Substrate 10
Polariser 35
38
36
39
37
SLM 1
3
2
21
23
25
26
24
Half wave plate function
(90 degree rotator) 32
Polariser
22

Figure 7

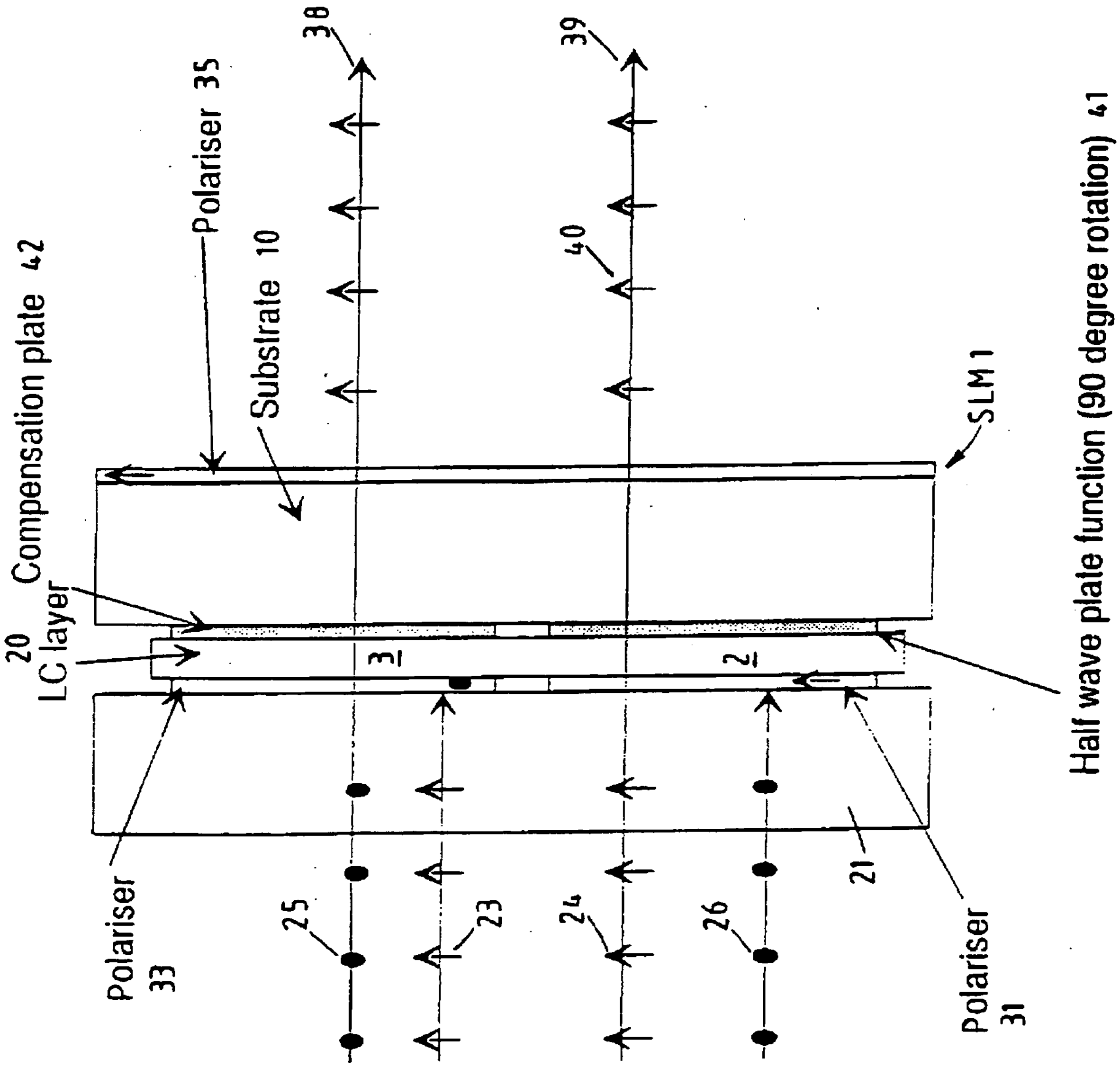
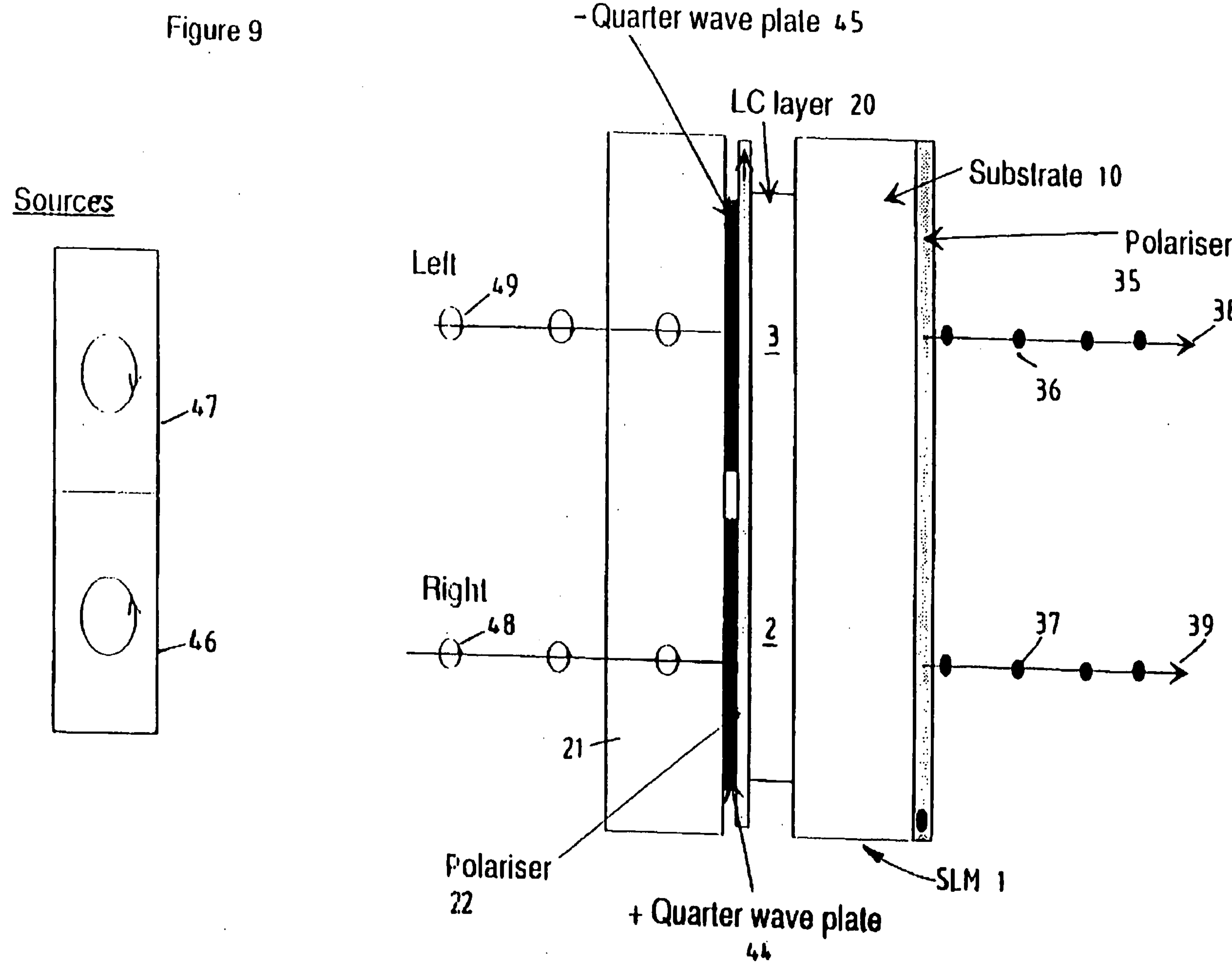
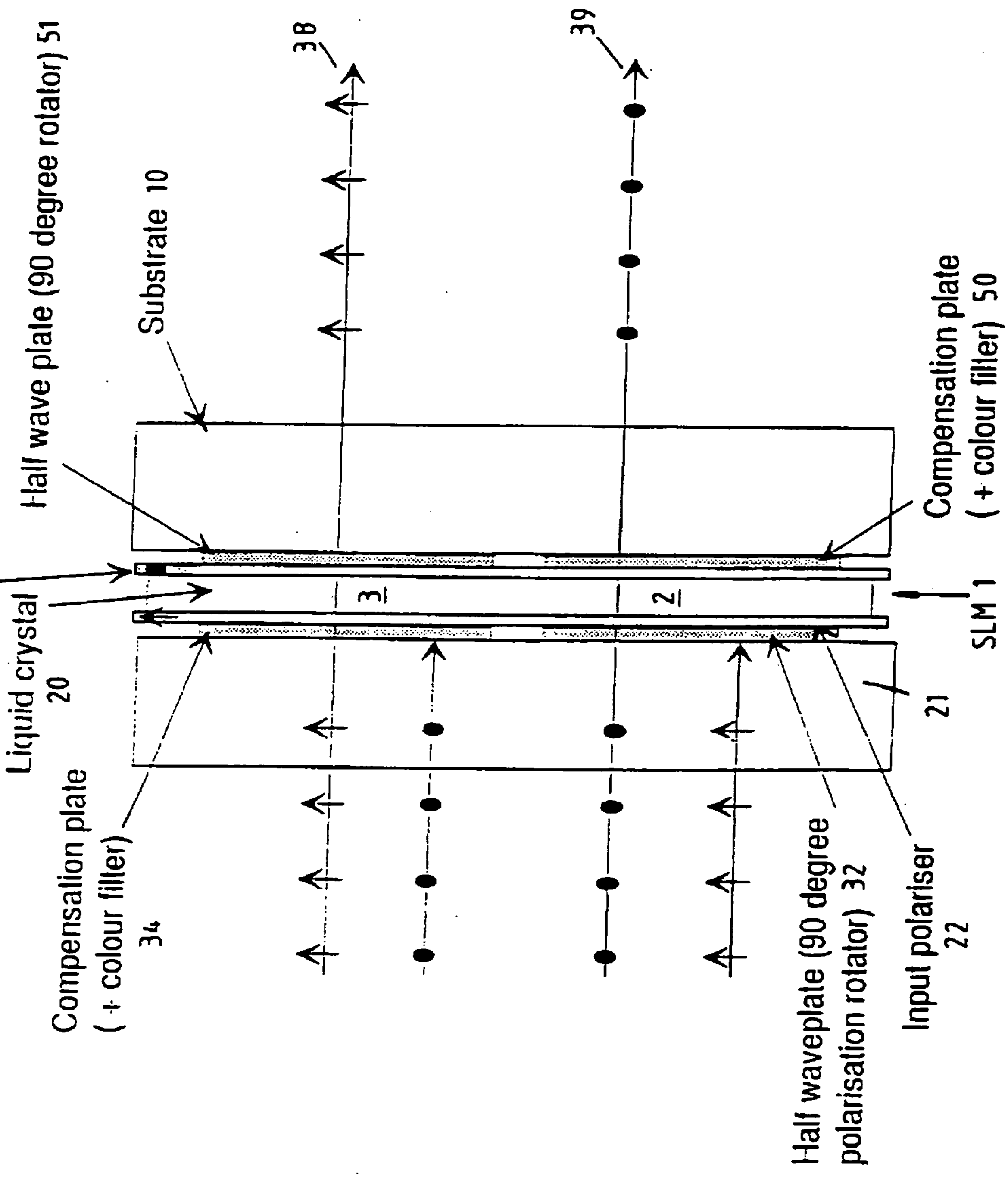

Compensation plate 42
Polariser 35
Substrate 10
38
39
40
SLM 1
20
LC layer
Half wave plate function (90 degree rotation) 41
Polariser
33
25
23
24
26
21
Polariser
31

Figure 8

Figure 9


Sources
47
46
Left
49
Right
48
21
Polariser
22
- Quarter wave plate 45
+ Quarter wave plate
44
LC layer 20
3
2
Substrate 10
Polariser
35
36
37
38
39
SLM 1



Polariser 35
Half wave plate (90 degree rotator) 51
Substrate 10
38
39
Liquid crystal 20
3
2
SLM 1
21
Compensation plate (+ colour filter) 50
Compensation plate (+ colour filter) 34
Half waveplate (90 degree polarisation rotator) 32
Input polariser 22

Figure 10

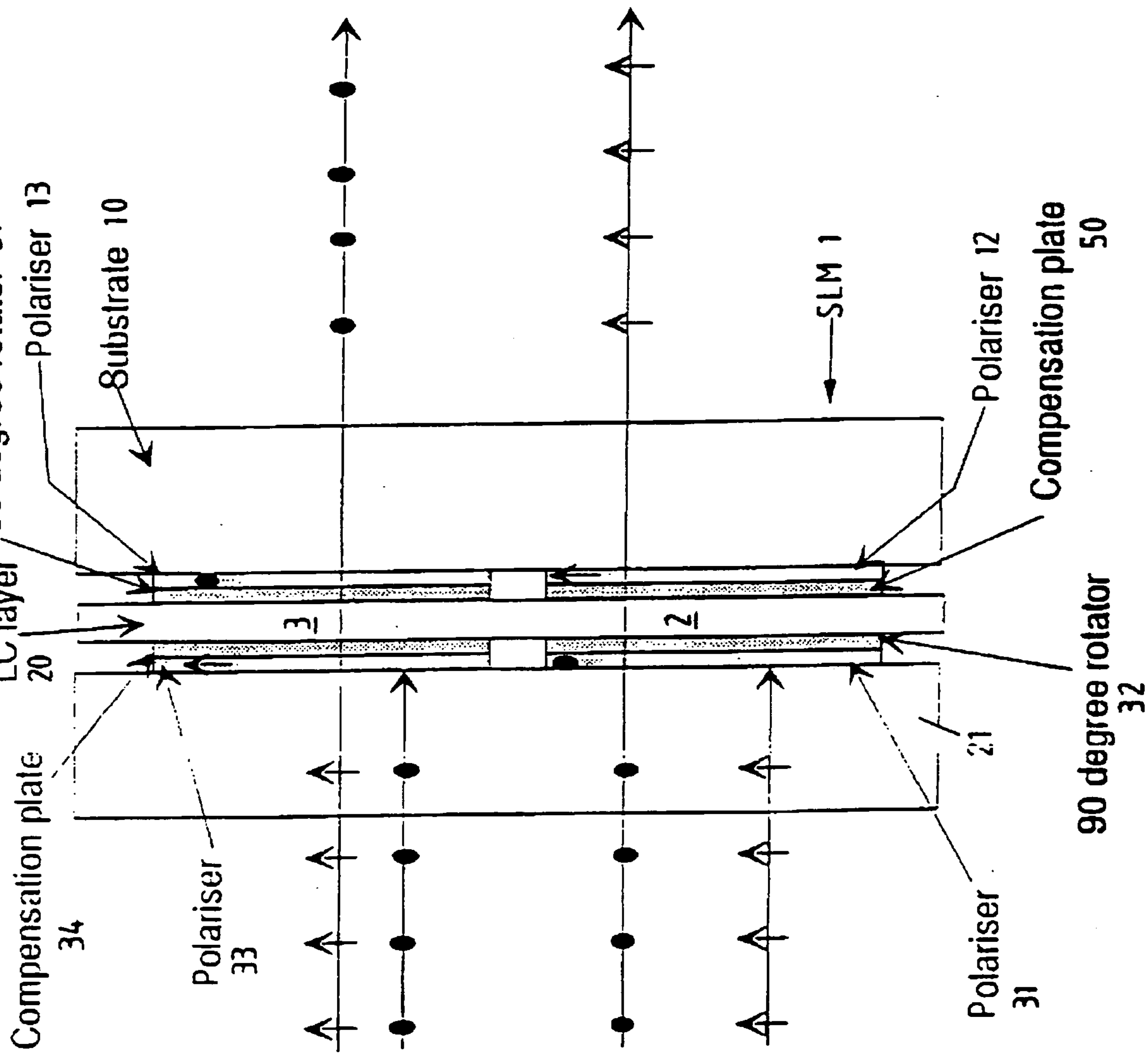
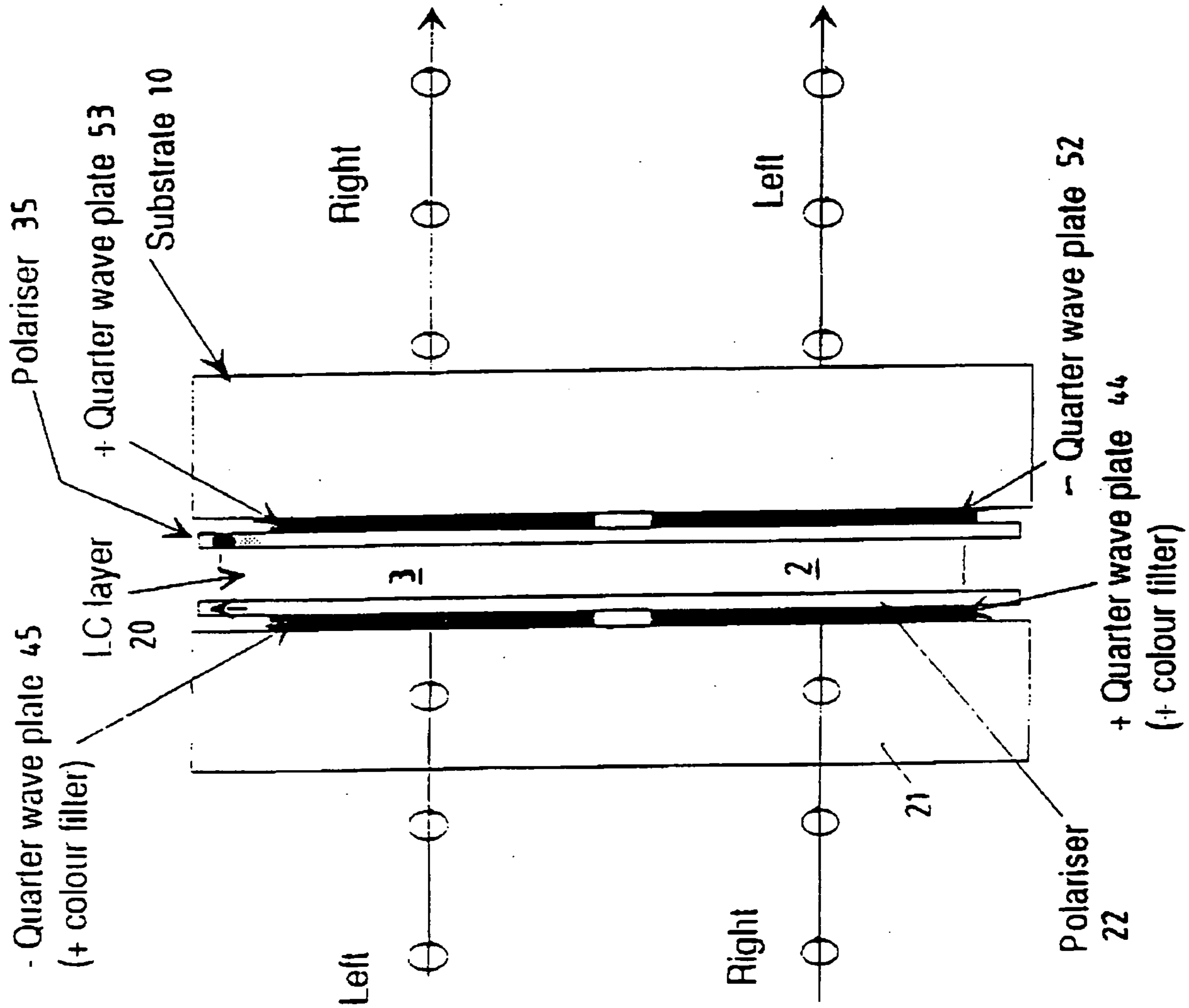

90 degree rotator 51
Polariser 13
Substrate 10
SLM 1
Polariser 12
Compensation plate 50
LC layer 20
3
2
Compensation plate 34
Polariser 33
21
90 degree rotator 32
Polariser 31

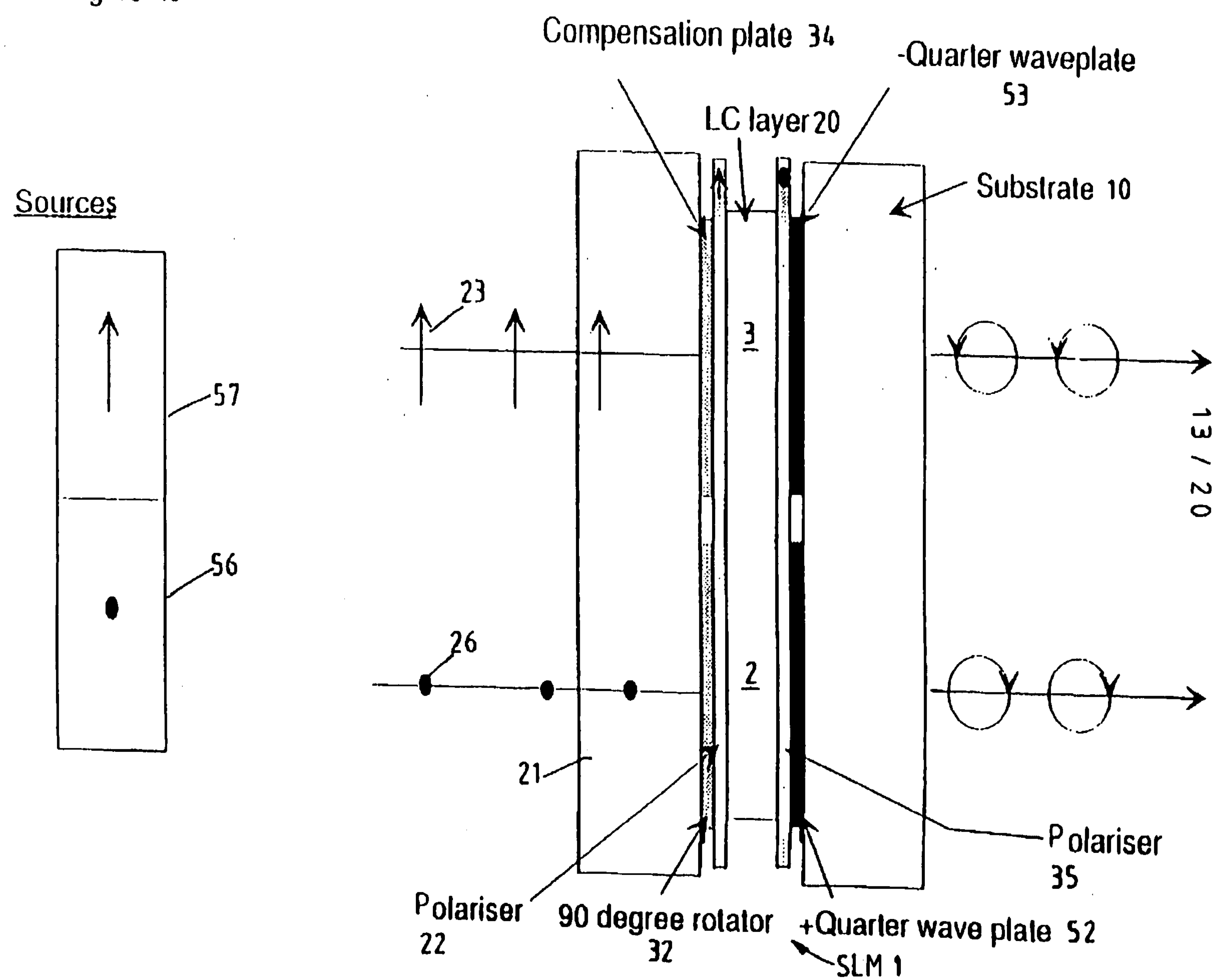
Figure 11

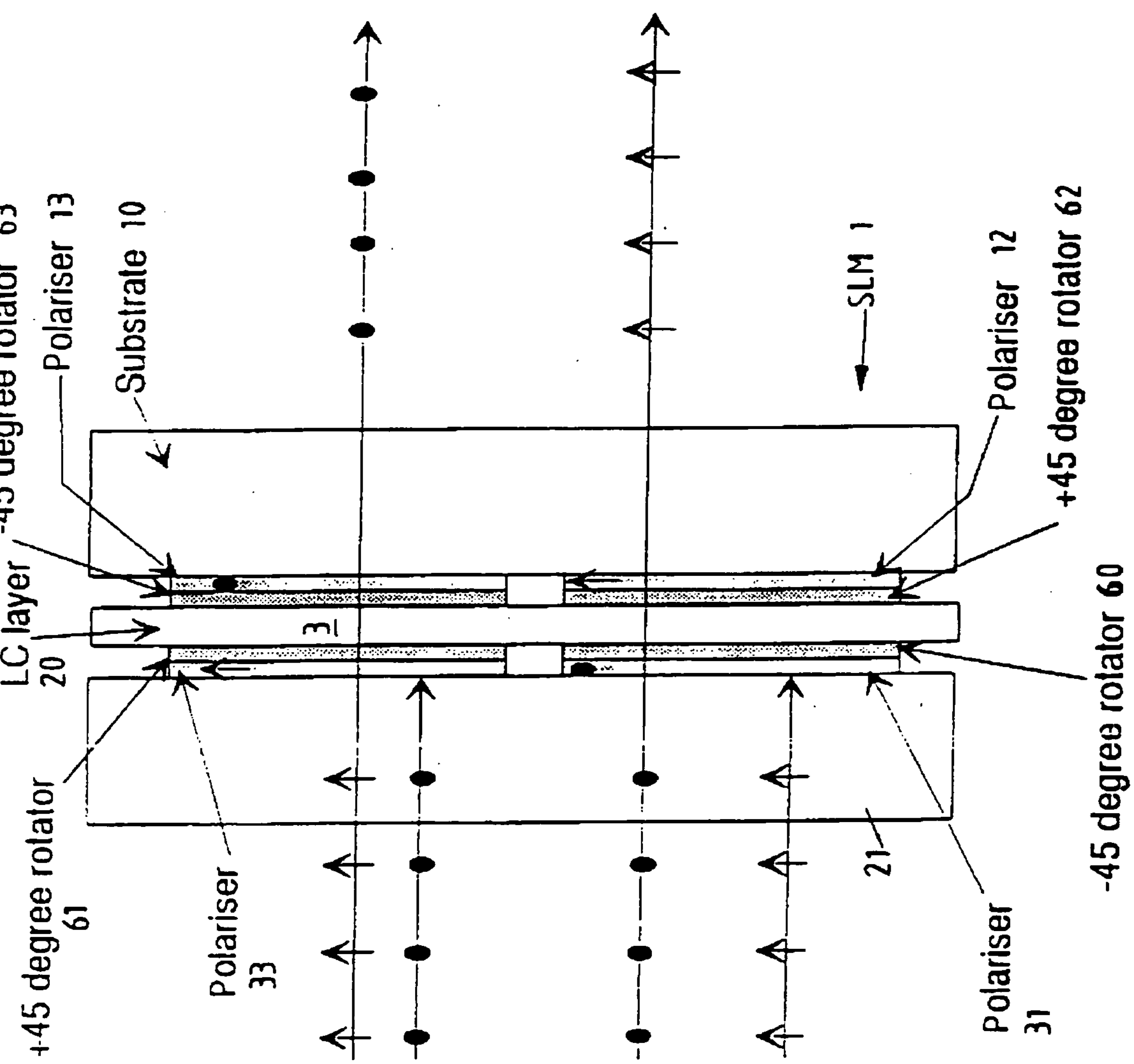


Polariser 35
+ Quarter wave plate 53
Substrate 10
Right
Left
LC layer 20
3
2
- Quarter wave plate 44
- Quarter wave plate 52
- Quarter wave plate 45
(+ colour filter)
+ Quarter wave plate 44
(+ colour filter)
21
Polariser 22
Left
Right

Figure 12

Figure 13

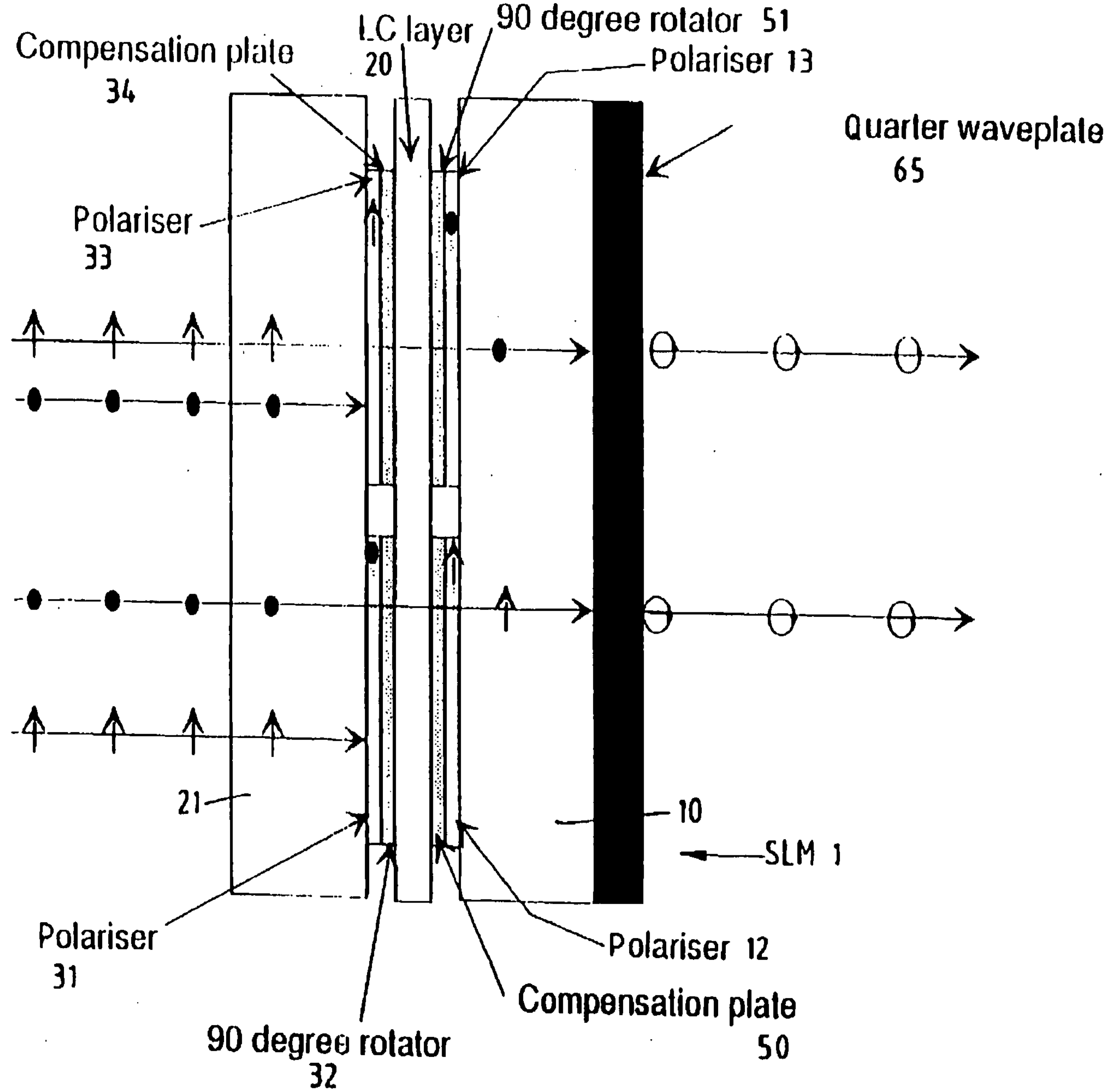

Sources
57
56
23
26
21
3
2
Compensation plate 34
LC layer 20
-Quarter waveplate 53
Substrate 10
Polariser 35
+Quarter wave plate 52
SLM 1
90 degree rotator 32
Polariser 22



-45 degree rotator 63
Polariser 13
Substrate 10
LC layer 20
31
+45 degree rotator 61
Polariser 33
SLM 1
Polariser 12
+45 degree rotator 62
-45 degree rotator 60
21
Polariser 31

Figure 14

Figure 15


Compensation plate
34
LC layer
20
90 degree rotator 51
Polariser 13
Quarter waveplate
65
Polariser
33
21
10
SLM 1
Polariser
31
90 degree rotator
32
Polariser 12
Compensation plate
50

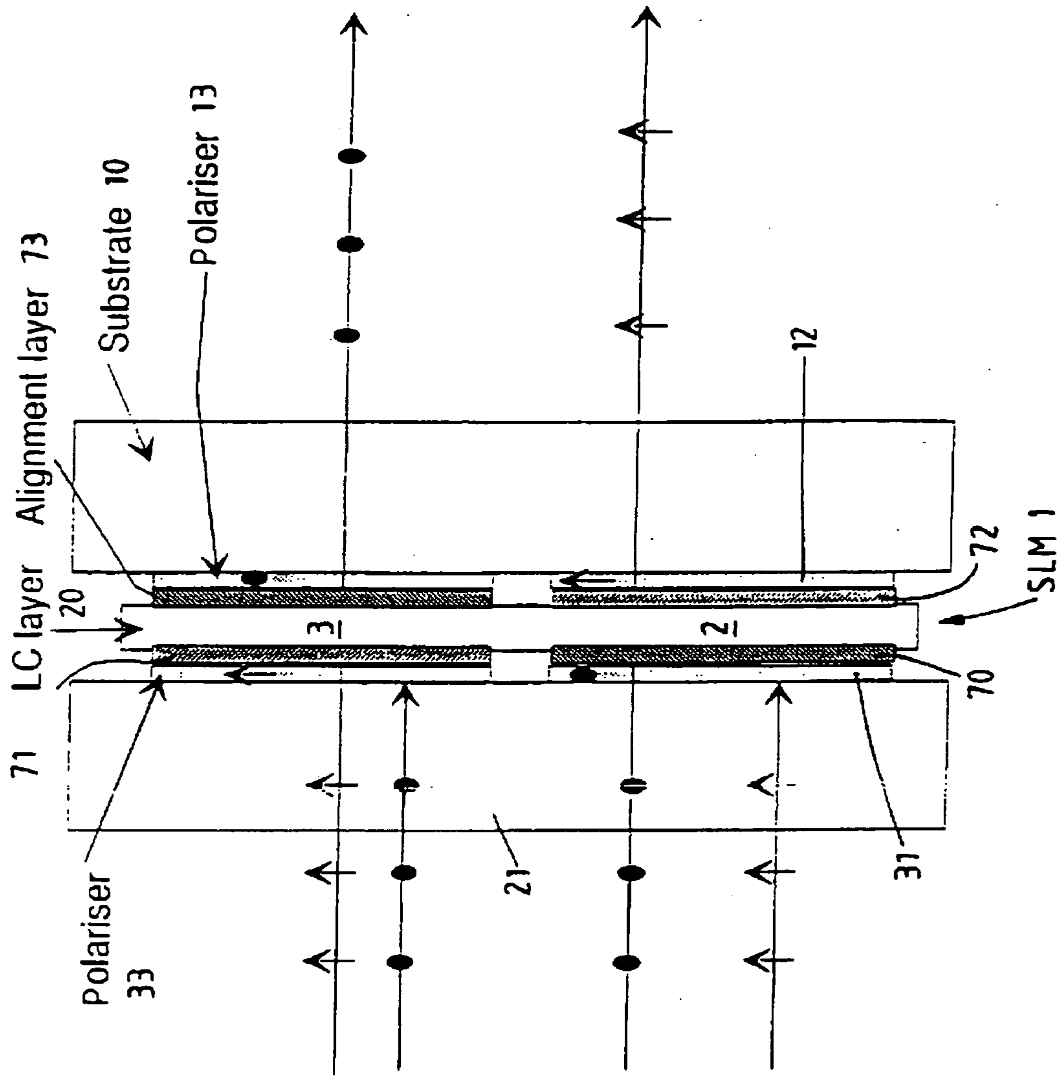

LC layer
20
Alignment layer 73
Substrate 10
Polariser 13
12
3
2
72
SLM 1
70
31
21
71
Polariser
33

Figure 16

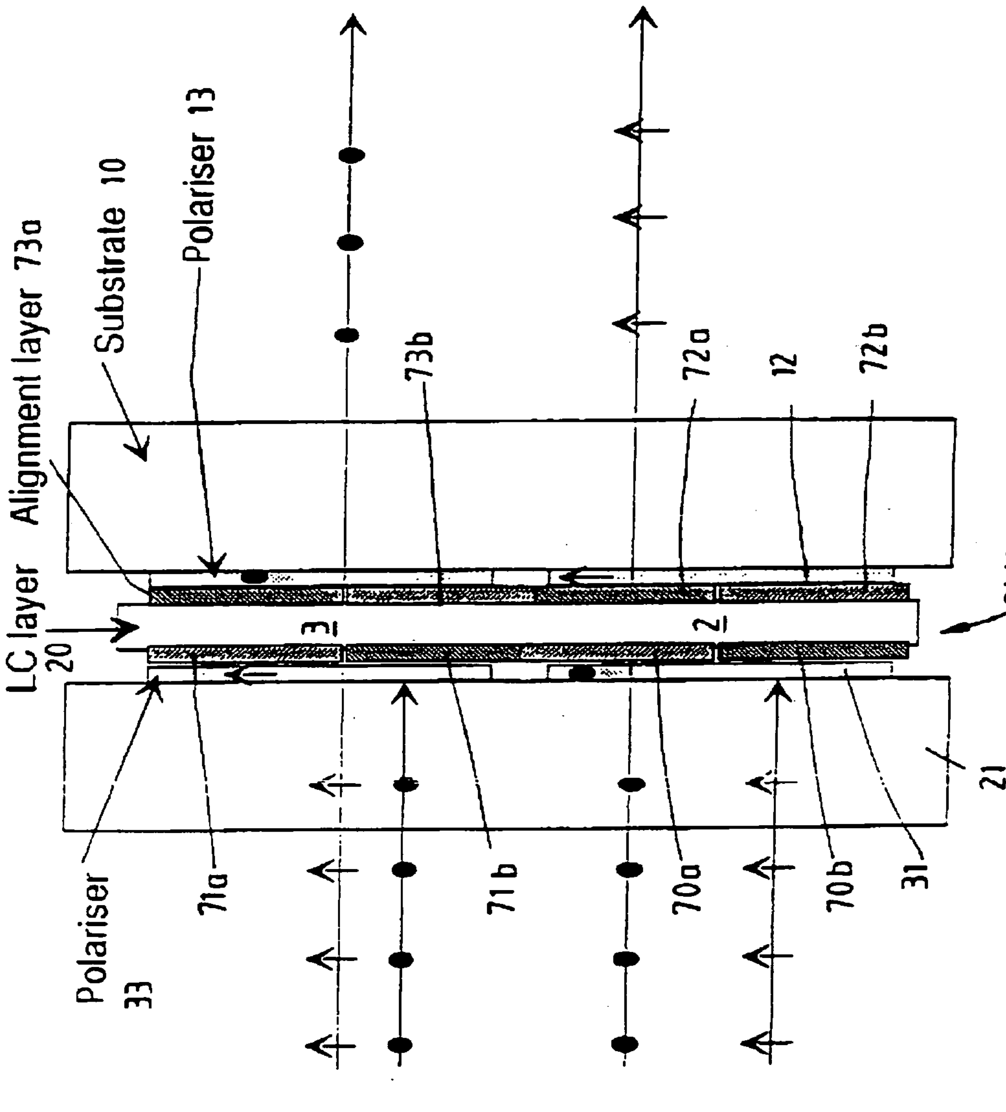

Polariser 13
Substrate 10
Alignment layer 73a
LC layer 20
73b
72a
12
72b
3
2
SLM 1
Polariser 33
71a
71b
70a
70b
31
21

Figure 17

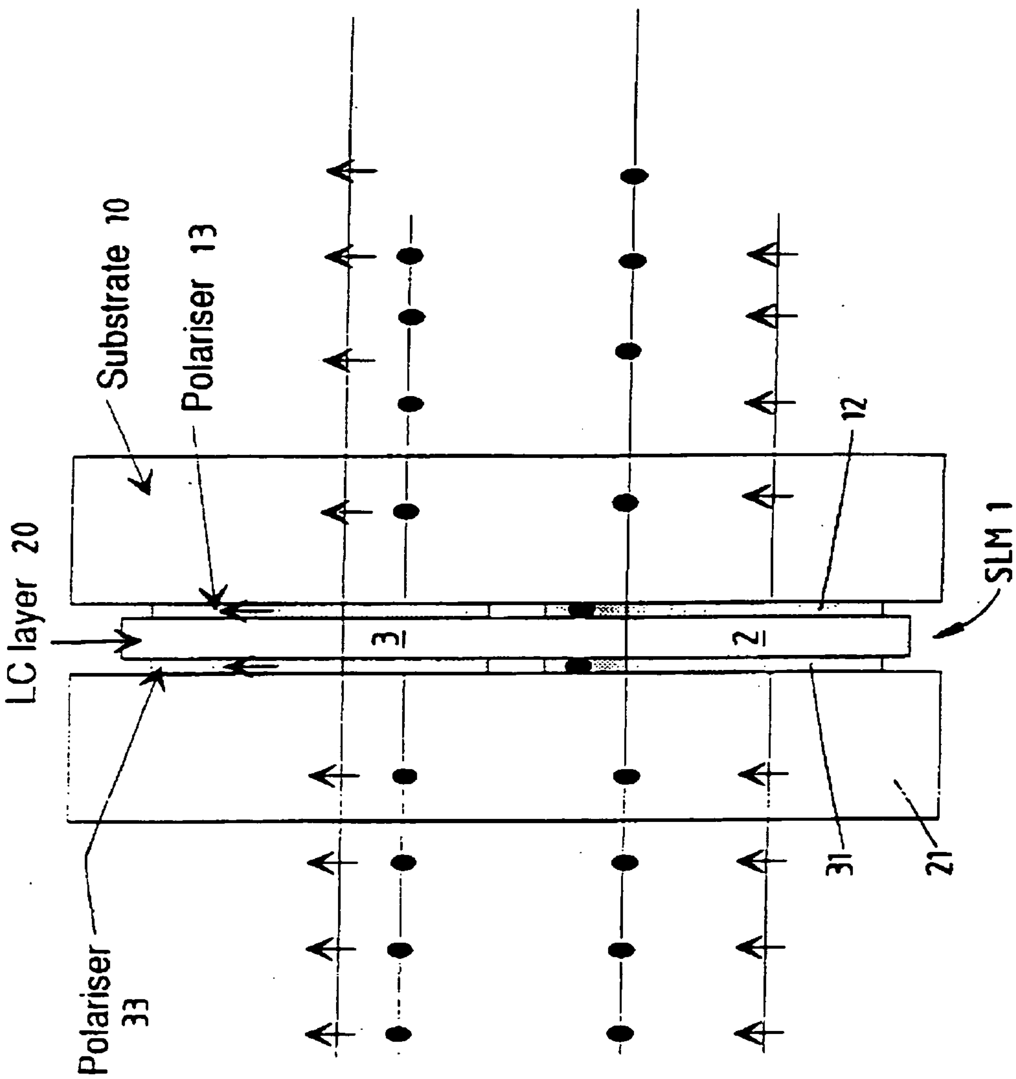

Substrate 10
Polariser 13
LC layer 20
Polariser 33
3
2
12
SLM 1
31
21

Figure 18

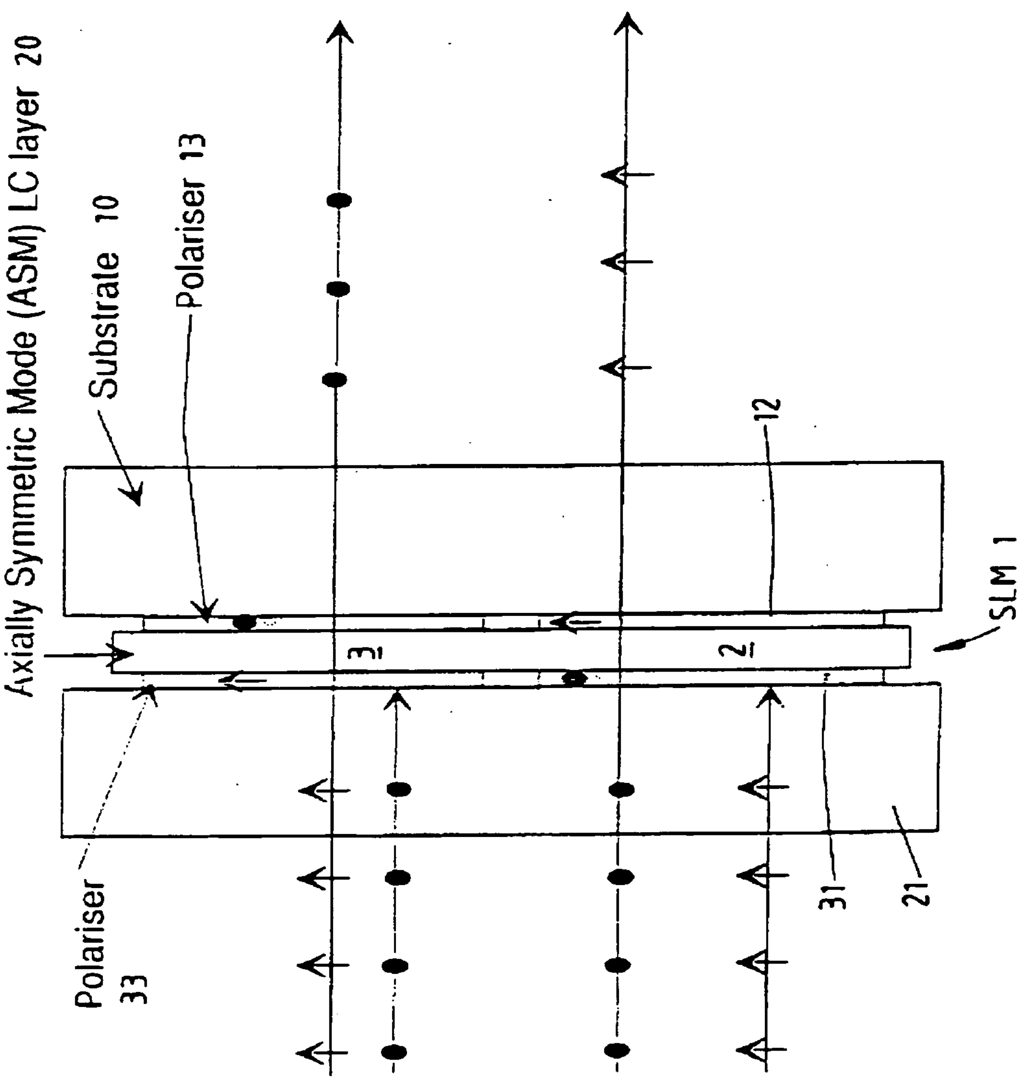
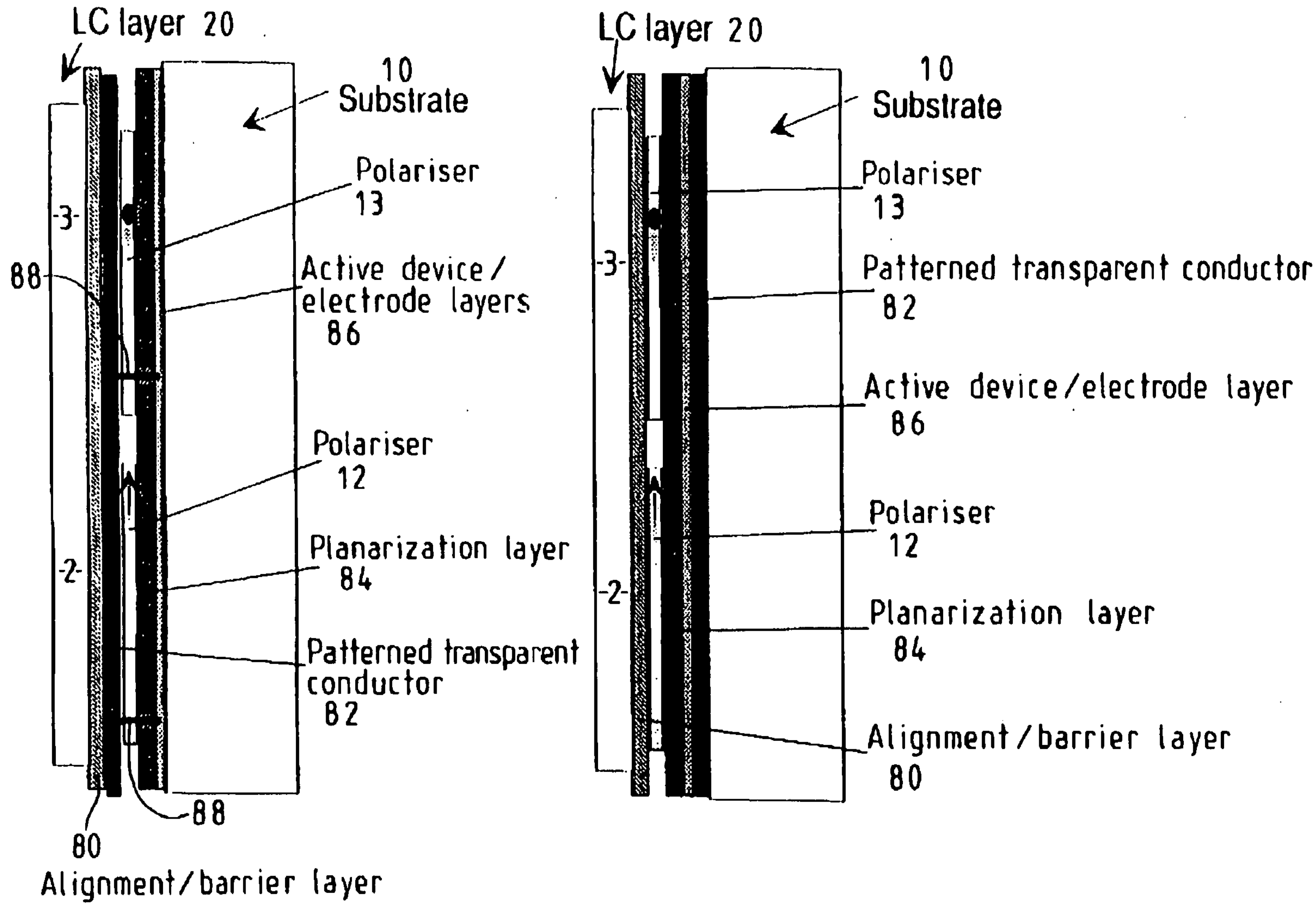

Axially Symmetric Mode (ASM) LC layer 20
Substrate 10
Polariser 13
12
SLM 1
3
2
Polariser 33
31
21

Figure 19

Figure 20


LC layer 20
10
Substrate
Polariser
13
Active device / electrode layers
86
Polariser
12
Planarization layer
84
Patterned transparent conductor
82
-3-
-2-
88
88
80
Alignment/barrier layer
LC layer 20
10
Substrate
Polariser
13
Patterned transparent conductor
82
Active device/electrode layer
86
Polariser
12
Planarization layer
84
Alignment/barrier layer
80
-3-
-2-

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SPATIAL LIGHT MODULATOR

The present invention relates to a spatial light modulator. Such a modulator may be used in three dimensional (3D) displays.

The term "mode" as used herein refers to the degree of attenuation of light by a liquid crystal element in the absence of an applied field across the liquid crystal. There are two such modes, namely a normally white mode in which there is low attenuation in the absence of an applied field and a normally black mode in which there is high attenuation in the absence of an applied field.

According to a first aspect of the invention, there is provided a spatial light modulator as defined in the appended Claim 1.

According to a second aspect of the invention, there is provided a spatial light modulator as defined in the appended Claim 28.

According to a third aspect of the invention, there is provided a spatial light modulator as defined in the appended Claim 29.

Preferred embodiments of the invention are defined in the other appended claims.

It is thus possible to provide a spatial light modulator which may be used in 3D displays and which suffers from substantially reduced parallax errors. For instance, cross talk, pseudoscopic viewing, and the imaging

of regions between pixels are all substantially reduced and a good off-axis viewing angle performance is provided. Further, all of the pixels have well-matched viewing angles. In particular, the contrasts of the pixels are well-matched throughout a large range of horizontal and vertical viewing positions.

It is further possible to provide a spatial light modulator which can be used in autostereoscopic 3D displays and stereoscopic 3D displays. Some embodiments can be used in these two types of 3D display by reversing the direction of light passing through the modulator. Others can be used in either type of display with the same direction of light so that switching between stereoscopic and autostereoscopic operation may be achieved by changing between polarised and non-polarised light sources.

Such spatial light modulators can provide high extinction ratios between polarisation states so as to give improved cross talk performance. Standard liquid crystal display alignment layer configurations may be used and the modulators may have a large number of components in common with existing liquid crystal devices. Thus, such modulators may be manufactured using a large number of the steps of existing liquid crystal display manufacturing techniques.

When a polariser is disposed on the outside of a spatial light modulator substrate, for instance as in conventional liquid crystal displays, the substrate must be highly isotropic to avoid any change in polarisation direction which would result in reduced extinction and therefore in reduced spatial light modulator contrast. Glass is typically used as the substrate so as to meet this requirement. There is a strong desire to use

plastic substrates for liquid crystal display fabrication so as to reduce weight. However, as is well known, many plastics are not optically isotropic. This is one reason why plastic liquid crystal displays have been difficult to produce economically.

By disposing the polariser inside a spatial light modulator, such as a liquid crystal display, the requirement for a highly isotropic substrate can be relaxed. This allows many cheaper plastics to be considered suitable for, for instance, a liquid crystal display substrate. Thus, embodiments of the present invention with internal polarisers have the further advantage of being able to use anisotropic substrates. For instance, if a plastic substrate is uniformly birefringent across its surface, then the birefringence can be accounted for in internal polarisation adjusting layers.

The invention will be further described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 illustrates diagrammatically a known stereoscopic display;

Figure 2 is a diagrammatic vertical section of the display of Figure 1 illustrating correct viewing;

Figure 3 is diagrammatic vertical section of the display of Figure 1 illustrating disadvantages of this display;

Figure 4 is a diagrammatic cross-sectional view of two adjacent pixels of a known spatial light modulator (SLM);

Figures 5 to 19 are diagrammatic cross-sectional views of two adjacent pixels of SLMs constituting first to fifteenth embodiments, respectively, of the invention; and

Figure 20 is a diagrammatic cross-sectional view of part of two adjacent pixels of an SLM constituting a sixteenth embodiment of the invention.

Like reference numerals refer to like parts throughout the drawings.

Figure 1 illustrates diagrammatically the operation of a stereoscopic 3D display of known flat panel polarisation type. The display comprises an SLM 1 formed by a liquid crystal device (LCD) and comprising a regular array of pixels (picture elements). The pixels are arranged as two sets of interlaced pixels with the pixels of the first set supplying light having a first direction of (linear or circular) polarisation and the pixels of the second set supplying light having the orthogonal polarisation. This is indicated by the different directions of shading in Figure 1. The pixels 2 of the first set display a first image of a stereoscopic pair for viewing by the left eye of an observer whereas the pixels 3 of the second set display an image for viewing by the right eye of the observer. A suitable unpolarised backlight (not shown) supplies light to the SLM 1.

In order for the observer to see the 3D stereoscopic image, analysing glasses 4 are worn. The glasses 4 comprise polarisers 5 and 6 for the left and right eyes, respectively, of the observer. The polarisation directions of the polarisers 5 and 6 match the output polarisations of the pixels 2 and 3 of the first and second sets, respectively. Thus, the polariser 5 passes the image encoded by the pixels 2 of the first set while greatly attenuating light from the pixels 3 of the second set whereas the polariser

6 passes light from the pixels 3 with relatively little attenuation while greatly attenuating light from the pixels 2.

In the case of linear polarisers, the cross talk performance degrades as the observer tilts his head because extinction by the polarisers 5 and 6 of light from the pixels 3 and 2, respectively, is reduced. Cross talk for the right eye of the observer whose head is tilted by an angle θ is given by:

$$I_L \cos^2(\pi/2-\theta)/I_R \cos^2\theta$$

where I_L and I_R are the light intensities for the left and right eyes, respectively. For a tilt angle of $\theta = 10°$, which is of the order of one full pupil height, the cross talk is 3%.

The use of circular polarisation techniques substantially eliminates cross talk caused by tilting of the head of the observer. However, circular polarisers tend to suffer from a poor base level of cross talk which is believed to be caused by limited optical bandwidth of circular polarisers.

As shown in Figures 2 and 3, the SLM 1 comprises a uniform rear polariser 8 and glass substrates 9 and 10 having a thickness of the order of 1 mm whereas the size of the pixels 2 and 3 is of the order of 100 micrometers. The pixels 2 and 3 are located on the internal surface of the substrate 10 whereas a micropolarising layer comprising polarising pixels 12 and 13 aligned with the pixels 2 and 3, respectively, is located on the external surface of the substrate 10. A black matrix of mask 17 which covers the gaps between the pixels, for instance where electrodes, transistors, and capacitors are located is intended to improve image contrast.

Figure 2 illustrates correct positioning of an observer eye 14 for viewing the 3D stereoscopic image. Light from a pixel displaying a left eye image element passes from the pixel 3a through the corresponding polarising pixel 13a and through the polarising glasses 5 to the observer eye 14. The observer eye 14 sees only the pixel 3a and the adjacent portion 17a of the black mask. The right eye (not shown) of the observer similarly sees only the pixels 2 and adjacent parts of the black mask 17.

The upper part of Figure 3 illustrates the view which the observer eye 14 has after moving upwardly with respect to the position illustrated in Figure 2. In this position, the eye 14 can see through the polarising pixel 13a to part of the pixel 3a which is aligned with the polarising pixel 13a. However, because of parallax errors resulting from the relatively thick substrate 10, the eye 14 can also see part of the pixel 2a through the polarising pixel 13a. Thus, the eye 14 sees pixels displaying both the left and right eye images of the stereoscopic pair, which results in substantial cross talk between these images and reduction in or loss of the 3D effect.

The lower part of Figure 3 illustrates the situation when the eye 14 has moved further vertically. In this case, the eye 14 can see the pixel 2b through the polarising pixel 13b. Thus, the left eye 14 sees the right eye pixel 2b. Similarly, the right eye sees the left eye pixel so that a pseudoscopic image is observed and the 3D effect is lost.

The observer thus has a very limited vertical viewing range if the 3D image is to be viewed stereoscopically with acceptable cross talk and image intensity and contrast ratio. If the micropolariser layer pixels are arranged as horizontal stripes freedom of observer movement will be

limited vertically whereas vertical stripes will result in limited horizontal freedom of movement. A "chequerboard" pixel arrangement will limit freedom of movement both horizontally and vertically. Even if an observer tracking system is provided to track the position of the observer and to swap the left and right images in order to prevent pseudoscopic viewing when the observer moves, cross talk and contrast degradation produced by the mechanism illustrated in Figure 3 still provides poor results for intermediate positions of the observer between image switching positions.

The known type of SLM shown in Figure 4 substantially avoids the problems created by parallax between the pixels 2 and 3 and the polarisation layer providing the polarisation pixels 12 and 13 by locating the polarisation pixels between the glass substrate 10 and a liquid crystal layer 20 which is shown as a twisted nematic liquid crystal (TN-LC) layer in Figure 4. By locating the output polarising pixels 12 and 13 substantially immediately adjacent the image pixels in the liquid crystal layer 20, the parallax problems illustrated in Figures 2 and 3 are substantially overcome.

The SLM 1 shown in Figure 4 further comprises a glass substrate 21 and an input polariser 22. Other elements, such as electrode layers and alignment layers, are not shown for the sake of clarity.

In use, the input polariser 22 passes light of a first linear polarisation at 23 and 24 to the pixels 2 and 3 whereas light of the orthogonal linear polarisation shown at 25 and 26 is greatly attenuated in accordance with the extinction ratio of the input polariser 22. In the drawings, the arrows

such as 23 and the dots such as 26 indicate orthogonal linear polarisations of transmitted light.

The pixel 2 has an input polariser formed by part of the polariser 22 and the output polariser 12 whose directions of polarisation are perpendicular to each other. Thus, the pixel 2 operates in the normally white mode i.e. transparent in the absence of an applied electric field across the liquid crystal layer of the pixel 2. This is because a standard TN-LC rotates the input polarisation by 90 degrees in the unpowered state. The pixel 3 has an input polariser formed by the aligned part of the polariser 22 and an output polariser 13 whose polarisation directions are parallel. Thus, the pixel 3 operates in the normally black mode i.e. substantially opaque in the absence of an applied electric field across the liquid crystal layer of the pixel 3.

As is well known, normally black and normally white pixels have different output grey levels with applied voltage. Accordingly, in order to provide matched performance for on-axis viewing, hardware or software corrections must be applied. This increases the complexity of the display.

Another problem with SLMs of the type shown in Figure 4 having pixels operating in the normally black and normally white modes is that the contrast performance varies with the angle of viewing away from the axial viewing position. For instance, for different vertical viewing positions of the observer, a matched contrast performance for the pixels 2 and 3 for on-axis viewing becomes substantially mismatched. This gives rise to differences in apparent brightness and contrast between the left and right eye views which change as an observer moves with respect

to the display. This can result in visual stress and false depth queues via the Pulfrich effect so that the effective observer viewing-position freedom for a display of the type illustrated in Figure 4 is again limited.

Figure 5 shows two adjacent pixels of an SLM constituting a first embodiment of the invention. The pixels 2 and 3 have input polarisers 31 and 33, respectively whose polarisation directions are perpendicular to each other. The input polarisers 31 and 33 form regions of a pixelated array of micropolarisers located at the internal surface of the substrate 21. A 90 degree rotator 32, which rotates the plane of linear polarisation by 90 degrees, is disposed between the input polariser 31 and the liquid crystal pixel 2. The rotator 32 may provide rotation by birefringence (e.g. a half waveplate), guiding, or a combination of the two and rotates the polarisation of light from the input polariser 31 by 90 degrees. A compensation plate 34 is disposed between the input polariser 33 and the liquid crystal pixel 3 to fill the gap which would otherwise occur between the input polariser 33 and the (constant thickness) liquid crystal layer 20 i.e. the compensation plate 34 can be optically isotropic, in which case it compensates for the thickness of the half waveplate function in the other group of pixels. However, it is also possible to use further compensation plates (not shown) which contain an anisotropic component (such as birefringence) which can further improve the viewing angle properties of the display. The compensation plate 34 may also be used to provide all or part of the anisotropic component for the associated pixel 3. The rotator 32 and the compensation plate 34 may include colour filtering in order to provide a colour display.

The surface of the substrate 10 which is external to the SLM carries a single layer non-pixellated output polariser 35.

With the direction of light through the SLM as shown by the arrows 38 and 39, the display may be operated in the autostereoscopic mode, for instance as disclosed in British Patent Application No. 9425607.0. A source of illumination (not shown) is located to the left of the SLM as shown in Figure 5 and comprises adjacent light sources, one of which produces light having the linear polarisation illustrated at 23 and 24 and the other of which produces light having the linear polarisation indicated at 25 and 26. Light having the polarisation 23 and 24 is passed by the input polariser 33 but substantially blocked by the input polariser 31 whereas the light having the polarisation 25 and 26 is substantially blocked by the input polariser 33 but passed by the input polariser 31. The rotator 32 rotates the polarisation of light by 90° so that the light passing into the liquid crystal pixels 2 and 3 has the same polarisation.

The output polariser 35 has a polarisation direction which is perpendicular to the polarisation direction of input light to both the pixels 2 and 3. Accordingly, both the pixels 2 and 3 operate in the normally white mode. The output polariser 35 effectively generates grey scale for each of the pixels 2 and 3 and the output light 36 and 37 has the same polarisation for all of the pixels. Light from the pixels 2 of the first set is directed to a first viewing window for the left eye of the observer whereas light from the pixels 3 of the second group is directed to a second viewing window for the right eye of the observer. With the eyes correctly positioned, the observer sees an autostereoscopic 3D image.

The input polarisers 31 and 33 and the rotator 32 are disposed substantially adjacent the liquid crystal layer 20 so that parallax problems for off-axis viewing of the image are substantially reduced or eliminated throughout a wide range of observer viewing positions. Because all of the pixels operate in the same normally white mode, contrast performances are substantially matched for a wide range of viewing positions of the observer.

By reversing the direction of light through the SLM shown in Figure 5, it may be used in a stereoscopic display. The illumination source may be a randomly polarised Lambertian backlight which is linear polarised by the polariser 35. Light from the liquid crystal pixel 2 is analyzed by the rotator 32 and the polariser 31 whereas light from the liquid crystal pixel 3 is analyzed by the polariser 33. The polarisation direction of light from the pixel 2 is therefore perpendicular to the polarisation direction of light from the pixel 3 and, by wearing suitable analysing glasses such as those shown in Figure 1, an observer sees a stereoscopic image throughout an extended viewing region without degradations caused by parallax and mismatched off-axis contrast performance.

Figure 6 shows an SLM 1 which differs from that shown in Figure 5 in that the rotator 32, the compensation plate 34, and the output polariser 35 are omitted and output polarisers 12 and 13 of the type shown in Figure 4 are provided in the form of a pixellated polarisation layer disposed between the liquid crystal layer 20 and the substrate 10.

With the direction of light as shown by the arrows 38 and 39 through the SLM 1, the SLM may be used as part of an autostereoscopic 3D display in the same way as the SLM shown in Figure 5. The input

polariser 31 passes light polarised in the direction 26 but blocks light polarised in the direction 24 whereas the input polariser 33 passes the light 23 but blocks the light 25. The pixels 2 and 3 operate in the normally white mode and the output polarisers 12 and 13 analyze the grey level, providing output light 36 and 40 with perpendicular polarisation directions. The observer does not need to wear analysing glasses for autostereoscopic viewing. However, by wearing such glasses with the left and right eye analyzer polarisation directions parallel to the polarisation directions of the output polarisers 12 and 13, respectively, residual cross talk at the eyes of the observer may be further reduced.

In fact, the SLM 1 shown in Figure 6 is symmetrical with respect to the direction of light therethrough and can be used in a stereoscopic 3D display since output light from the pixels 2 has a polarisation direction perpendicular to that of output light from the pixels 3.

Figure 7 shows an SLM 1 which differs from that shown in Figure 5 in that the input polarisers 31 and 33 are replaced by a non-pixellated input polariser 22 disposed between the rotator 32 and the compensation plate 34 on the one side and the liquid crystal layer 20 on the other side.

For autostereoscopic operation, the light 23 and 25 from the polarised light sources passes through the compensation plate to the input polariser 22, which passes the light 23 and blocks the light 25. The rotator 32 rotates the polarisation of the light 24 and 26 so that the light 24 is blocked by the input polariser 22 but the light 26, following rotation, is passed to the liquid crystal pixel 2. The output polariser 35 analyses the grey scale from the pixels 2 and 3.

In the stereoscopic mode, light from a randomly polarised source passes in the opposite direction through the SLM 1. The output light from the liquid crystal pixels 2 and 3 is polarised by the polariser 22 and supplied direct from the pixel 3 while being rotated by 90 degrees by the rotator 32 of the pixel 2.

A manufacturing advantage of the embodiment of Figure 7 compared with that of Figure 5 is that only one pixellated layer, namely that comprising the rotator 32 and the compensation plate 34, is required. The internal polariser need not be pixellated. Thus, the number of mask steps during manufacture may be reduced.

Figure 8 shows an SLM 1 which differs from that shown in Figure 5 in that the rotator 32 and compensation plate 34 are omitted and a 90 degree rotator 41 and a compensation plate 42 are provided. The rotator 41 is disposed between the liquid crystal layer 20 of the pixel 2 and the substrate 10 whereas the compensation plate 42 is disposed between the liquid crystal layer 20 of the pixel 3 and the substrate 10.

For autostereoscopic operation with orthogonally polarised light sources, the input polarisers 31 and 33 pass light of orthogonal polarisations. Light from the pixel 3 is analyzed directly by the output polariser 35 whereas light from the pixel 2 is rotated by 90° by the rotator 41 and analyzed by the output polariser 35. Thus, both pixels 2 and 3 operate in the normally white mode.

For stereoscopic operation, the direction of light through the SLM 1 is reversed and the polarisers 31 and 33 supply light of orthogonal polarisations.

Figure 9 shows an SLM 1 which differs from that shown in Figure 7 in that the rotator 32 and the compensation plate 34 are replaced by a +quarter waveplate 44 and a -quarter waveplate, respectively.

Figure 9 illustrates autostereoscopic operation of the SLM 1. Light sources 46 and 47 provide right-handed and left-handed circularly polarised light, respectively. The combination of the plate 44 and the input polariser 22 passes the right-handed polarised light 48 from the light source 46 but blocks the left-handed polarised light from the source 47. Similarly, the plate 45 and the input polariser 22 pass left-handed circularly polarised light from the light source 47 but block light from the source 46. The pixels 2 and 3 both operate in the normally white mode.

For stereoscopic operation, light passes through the SLM 1 in the opposite direction. Randomly polarised input light is polarised by the polariser 35 and analyzed by the polariser 22. The plates 44 and 45 convert the output light to right-handed and left-handed circularly polarised light, respectively, which may then be analyzed by suitable analysing glasses.

Figure 10 shows an SLM 1 which differs from that shown in Figure 7 in that the output polariser 35 is disposed next to the liquid crystal layer 20, a compensation plate 50 is disposed between the output polariser 35 and the substrate 10 for the pixel 2 and, for the pixel 3, a 90 degree rotator 51 is disposed between the output polariser 35 and the substrate 10.

For autostereoscopic operation as illustrated in Figure 10, operation of the SLM differs from that of Figure 7 in that the polarisation of light from the pixel 3 is rotated by 90 degrees. Thus, an observer sees the 3D

image without requiring any viewing aids. However, because the left and right views have orthogonal directions of polarisation, the observer may wear suitable analysing glasses in order to reduce residual cross talk in the autostereoscopic mode.

The SLM 1 of Figure 10 may be used in a stereoscopic display with light passing in the same direction as during autostereoscopic operation. In fact, the SLM of Figure 10 is symmetrical with respect to the direction of passage of light. Thus, the display may be switched between autostereoscopic and stereoscopic operation merely by changing between perpendicularly polarised light sources for autostereoscopic operation and a randomly polarised light source for stereoscopic operation.

In the embodiment shown in Figure 10, each of the pixels 2 and 3 has a compensation plate/rotator pair so that any performance degradations which occur in these components are balanced between the pixels 2 and 3. As in all of the embodiments described herein, appropriate colour filters may be provided substantially adjacent the liquid crystal pixels 2 and 3 so as to avoid parallax effects.

The SLM 1 shown in Figure 11 differs from that shown in Figure 10 in that the input and output polarisers 22 and 35 are omitted and are replaced by pixellated polarising layers adjacent the substrates 21 and 10. The pixel 2 is thus provided with an input polariser 31 and an output polariser 12 whereas the pixel 3 is provided with an input polariser 33 and an output polariser 13. The SLM of Figure 11 may be used in the same way as the SLM of Figure 10 for stereoscopic and

autostereoscopic operation and, with suitable analysing glasses, for reduced cross talk autostereoscopic operation.

Figure 12 illustrates an SLM 1 which differs from that shown in Figure 9 in that the output polariser 35 is disposed adjacent the liquid crystal layer 20, the pixel 2 is provided with a -quarter waveplate 52, and the pixel 3 is provided with a +quarter waveplate 53.

For autostereoscopic operation, the SLM of Figure 12 is illuminated by polarised light sources such as the sources 46 and 47 shown in Figure 9. The output light from the pixels 2 and 3 is analyzed by the output polariser 35 and then converted to circular polarisation of opposite handedness by the plates 52 and 53. The observer can view the 3D image autostereoscopically without any viewing aids or may wear suitable analysing glasses so as to improve the cross talk performance.

For stereoscopic operation, randomly polarised light is polarised by the input polariser 22 and analyzed by the output polariser 35. The output light is then converted to circularly polarised light of opposite handedness and the 3D image can be viewed by an observer wearing suitable analysing glasses.

The structure of the SLM shown in Figure 12 is symmetrical with respect to the direction of light passing therethrough. Accordingly, changing between stereoscopic and autostereoscopic operation may be achieved by changing between polarised and unpolarised light sources.

The SLM 1 shown in Figure 13 differs from that shown in Figure 12 in that the + and -quarter waveplates 44 and 45 are replaced by a 90

degrees rotator 32 and a compensation plate 34, respectively. For autostereoscopic operation, linearly polarised light sources 56 and 57 having orthogonal polarisation directions are used in place of the circularly polarised light sources 46 and 47 of Figure 9. The input polariser 22 passes light having the polarisation 23 from the source 57 while blocking light having the polarisation 26 from the source 56. The combination of the rotator 32 and the input polariser 22 passes light having the polarisation 26 from the source 56 while blocking light having the polarisation 23 from the source 57. The output polariser 35 analyses grey scale from the pixels 2 and 3 and the waveplates 52 and 53 convert the output light from the pixels 2 and 3 to circularly polarised light of opposite handedness. The observer sees the 3D image without having to wear viewing aids or may wear suitable analysing glasses so as to reduce residual cross talk.

For stereoscopic operation, the light sources 56 and 57 are replaced by a randomly polarised Lambertian light source. Light from the light source is polarised by the polariser 22, analyzed by the polariser 35, and converted by the waveplates 52 and 53 to circularly polarised light of opposite handedness. The observer wears suitable analysing glasses in order to see the 3D image. As previously described, the use of circularly polarised output light means that the cross talk performance is not affected by tilting of the head of the observer.

The SLM 1 shown in Figure 14 differs from that shown in Figure 11 in that the 90 degree rotator 32 is replaced by a -45 degree rotator 60, the compensation plate 34 is replaced by a +45 degree rotator 61, the compensation plate 50 is replaced by a +45 degree rotator 62 and the 90 degree rotator 51 is replaced by a -45 degree rotator 63.

For autostereoscopic operation, linearly polarised light sources such as those shown in Figure 13 are used. The input polarisers 31 and 33 pass light of orthogonal linear polarisations and the rotators 60 and 61 rotate the polarisations so that the light applied to the liquid crystal layer of the pixels 2 and 3 is of the same linear polarisation. The combinations of the output polarisers 12 and 13 and the rotators 62 and 63 analyze light of the same polarisation from the liquid crystal layer 20 for the pixels 2 and 3 and provide output light from the pixels of orthogonal linear polarisations. The 3D image can be viewed without viewing aids or via suitable analysing glasses for reducing residual cross talk. For stereoscopic operation, randomly polarised light is polarised by the input polarisers 31 and 33 and the orthogonally polarised output light is analyzed by suitable analysing glasses.

The arrangement of Figure 14 may be advantageous because of the use of balanced rotators at each polarisation stage. Any viewing angle differences of the rotators are effectively reduced by the use of matched pairs of rotators for each of the pixels 2 and 3.

The SLM 1 shown in Figure 15 differs from that shown in Figure 11 in that an output broadband quarter waveplate 65 is disposed on the external surface of the substrate 10. Operation of the SLM of Figure 15 differs in that the orthogonal linear output polarisations of the SLM shown in Figure 11 are converted to orthogonal circular polarisations. Similarly, a broad band quarter waveplate may be placed on the external surface of the substrate 21 for use with circularly polarised light sources for autostereoscopic operation.

Although not explicitly shown in the embodiments described hereinbefore, it is implicit that alignment layers for the liquid crystal of the layer 20 are uniform throughout the extent of the layer. Figure 16 shows a spatial light modulator 1 of the type shown in Figure 6 in which alignment layers 70 to 73 for the pixels 2 and 3 are explicitly shown. In this embodiment, the alignment layers have alignment directions which are different for the pixels 2 and 3. Thus, the alignment layer 70 has an alignment direction which is parallel to the absorbing axis of the polariser 31 whereas the alignment layer 71 of the pixel 3 has an alignment direction which is parallel to the absorbing axis of the polariser 33. Similarly, the alignment directions of the layers 72 and 73 are parallel to the absorbing axes of the polarisers 12 and 13, respectively. Thus, the alignment directions of the layers 70 and 71 of the pixels 2 and 3 are perpendicular to each other. This arrangement improves the matching of the angular contrast performance of the pixels 2 and 3 compared to using a uniform alignment layer as shown in Figure 6. The angular contrast in this arrangement is improved with respect to arrangements in which the alignment directions are perpendicular to the absorbing axes of the associated polarisers.

The SLM 1 shown in Figure 17 differs from that shown in Figure 16 in that a multi-domain liquid crystal alignment is provided within each of the pixels 2 and 3. In the arrangement shown by way of example in Figure 17, each of the alignment layers is divided into two portions (indicated by subscripts a and b) having mutually perpendicular alignment directions. Such an arrangement has the effect of matching the angular viewing contrast performances of the pixels 2 and 3 by an averaging process. More complex domain structures within each pixel may also be used.

In all of the embodiments described hereinbefore, operation of all of the pixels 2 and 3 has been in the normally white mode. However, each of these embodiments may be operated in the normally black mode and Figure 18 shows an SLM 1 of the type shown in Figure 6 but modified for normally black operation. In particular, the polarisers 12 and 31 of the pixel 2 have parallel polarisation directions and the polarisers 13 and 33 of the pixel 3 have parallel polarisation directions when the TN-LC effect is used. The other embodiments may be modified similarly so that output polarisation from the liquid crystal layer is analyzed parallel to the input polarisation of light to the layer 20.

Similarly, optically active compensation plates may be provided in any of the embodiments, for instance so as to improve viewing range and angular contrast.

Although the embodiments disclosed hereinbefore have been implicitly described with respect to twisted nematic liquid crystal layers, embodiments may readily be provided which use super twisted nematic liquid crystals and variable birefringence liquid crystal techniques such as electrically controlled birefringence or π cells. Further, complex compensation plates may be provided to match the birefringence for off-axis light passing through the different sets of pixels of the display. Such compensation plates may include a negative retardance component and may include guiding components of appropriate handedness of twist to improve and/or match the angular viewing contrast.

Figure 19 illustrates an SLM 1 which differs from that shown in Figure 6 in that the liquid crystal layer 20 is operated in the axially symmetric mode, for instance as described by N. Yamada et al, "Axially Symmetric

Mode", SID95 Digest. In particular, the axially symmetric mode (ASM) establishes a radial or coaxially oriented liquid crystal alignment which is different from the linear alignment of the standard TN-LC effect. In particular, it is possible to achieve this ASM alignment without the polyimide alignment layer, which requires high temperature processing.

Image inversion (sometimes called contrast inversion) can occur when conventional displays are viewed substantially off-axis. When compared with the relative lightness on-axis, the same grey levels can have the opposite relative lightness off-axis because of the effect of the birefringence of the liquid crystal. Thus, parts of the image appear like in a photographic negative or contrast inverted image. The polarisers are set to give matched angular viewing contrast and to preserve the excellent angular viewing properties of the axially symmetric mode. Further compensation plates (not shown) may be added to preserve the exceptionally wide viewing angle and freedom from "image inversion" properties inherent in the axially symmetric mode and/or to improve the matching of the off-axis contrast performances of the pixels 2 and 3.

As is well known, polarisers can be damaged by ultraviolet light and usually include an ultraviolet protecting film. With appropriately shaped micropolariser patterns, this film may be used to form all or part of an ultraviolet exposure mask, for instance for use in the fabrication of an axially symmetric mode SLM. In addition, the ultraviolet shielding and polarising properties of the micropolariser have to be considered in order to allow the formation of polymer walls around each pixel.

The axially symmetric mode may be used in other embodiments, in particular in autostereoscopic and stereoscopic displays with the SLM of Figures 7 and 9 and in stereoscopic displays with the SLM of Figure 8.

A transparent conductor electrode may be located between the optical components and the substrate or between the optical components and the liquid crystal layer. In the former case, the effect of the additional dielectric layers in series with the liquid crystal layer has to be taken into account, for instance on the required drive voltage from an active matrix element.

The left part of Figure 20 illustrates an arrangement in which an (optional) alignment/barrier layer 80 is disposed between the liquid crystal layer 20 and a patterned transparent conductor 82. This arrangement is of the type comprising polarisers 12 and 13 which are disposed between the conductor 82 and a planarisation layer 84. One or more (optional) active device/electrode layers 86 are formed on the substrate 10 and are overlayed by the planarisation layer 84. The conductor 84 is thus disposed between the optical components 12, 13 and the liquid crystal layer 20 but is separated from the active drive/electrode layers 86. Accordingly, suitable through connections 88 are provided between the conductor 82 and the layers 86.

The right part of Figure 20 illustrates an arrangement which differs from that shown in the left part of Figure 20 in the order of layers between the liquid crystal layer 20 and the substrate 10. Thus, the patterned transparent conductor 82 is disposed on the substrate 10 and is overlayed by the active device/electrode layer 86, which in turn is provided with the planarisation layer 84. The conductor 82 is thus

connected directly to the layer 86 and does not require the through connections 88. However, because the optical components 12, 13 and the layers 84 and 86 are disposed between the conductor 82 and the liquid crystal layer 20, the drive voltage may have to be increased for correct operation of the display.

In the event that displays using SLMs of the type disclosed herein are required not only to provide 3D images but also 2D images, the 2D image will have the full resolution of the SLM. This is advantageous compared with autostereoscopic 3D displays of the lenticular or parallax barrier type, in which the 2D display resolution is a fraction of the SLM resolution.

In SLMs required to provide a colour display, as mentioned hereinbefore, colour filters may be incorporated near the liquid crystal layer so as to minimise parallax effects. Wavelength dependent components such as quarter waveplates, 90 degree rotators, 45 degree rotators may then be tuned to the colour filter associated with each pixel of the display.

In the embodiments described hereinbefore, the rotation functions may be provided by birefringence or guiding or a combination of the two. Both the rotation and the compensation elements may also be composite devices formed from more than one layer in order to increase the optical band width of the devices or to improve further the range/matching of angular viewing cones of the groups of pixels.

The embodiments described hereinbefore all include optical elements which have to be incorporated within the LCD itself. The materials of which these elements are made must therefore be capable of enduring

the processing temperature and environment associated with LCD fabrication without significant degradation. As is well known, some though not all LCDs use alignment layers to promote or stabilise the liquid crystal orientation. Some known types of alignment layer require processing at temperatures in the vicinity of 200°C and the materials of the optical elements must endure these temperatures without substantial degradation.

Although not limited to active matrix displays, this important class of display introduces some additional fabrication issues compared with passive matrix displays. In particular, the additional components must not introduce unacceptable contamination into the liquid crystal material which might effect important properties, such as the holding ratio. Barrier layers may therefore be used to help protect the liquid crystal material from degradation.

Further, the processing temperature of an active matrix substrate can be higher than that of a counter electrode. Thus, it may be advantageous to adopt structures described hereinbefore where components such as the polarisers may be disposed on the outside of the active matrix substrate rather than the counter electrode.

In various of the embodiments described hereinbefore, specific values of angular rotation of the polarisation vectors have been described. However, it is the relative rotations between the two groups of pixels which are important. For instance, rotations of -30° and +60° are equivalent to rotations of 0° and 90° as are rotations of 90° and 180°.

CLAIMS

1. A spatial light modulator comprising first and second substrates and a liquid crystal disposed therebetween, the modulator comprising a plurality of pixels arranged to operate in the same mode and each comprising a polarisation adjuster disposed between the first substrate and the liquid crystal, the pixels being arranged as first and second sets, the polarisation adjusters of the pixels of the first set being arranged to transmit light of a first polarisation from the first substrate to the liquid crystal and the polarisation adjusters of the pixels of the second set being arranged to transmit light of a second polarisation different from the first polarisation from the first substrate to the liquid crystal.

2. A modulator as claimed in Claim 1, in which the pixels of the first set are interleaved with the pixels of the second set.

3. A modulator as claimed in Claim 1 or 2, in which the second polarisation is substantially orthogonal in the first polarisation.

4. A modulator as claimed in any one of the preceding claims, in which the first and second polarisations are linear polarisations.

5. A modulator as claimed in Claim 3, in which the first and second polarisations are circular polarisations of opposite direction.

6. A modulator as claimed in any one of the preceding claims, in which the pixels are arranged to operate in the normally black mode.

7. A modulator as claimed in any one of Claims 1 to 5, in which the pixels are arranged to operate in the normally white mode.

8. A modulator as claimed in any one of the preceding claims, in which the polarisation adjuster of each of the pixels of the first set comprises a first linear polariser having a first polarisation direction and the polarisation adjustor of each of the pixels of the second set comprises a second linear polariser having a second polarisation direction substantially perpendicular to the first polarisation direction.

9. A modulator as claimed in Claim 8, in which each pixel of the first set comprises a third linear polariser having a third polarisation direction disposed between the liquid crystal and the second substrate and each pixel of the second set comprises a fourth linear polariser having a fourth polarisation direction substantially perpendicular to the third polarisation direction disposed between the liquid crystal and the second substrate.

10. A modulator as claimed in Claim 8, in which each pixel of the second set comprises a first 90 degree rotator disposed between the liquid crystal and the second substrate.

11. A modulator as claimed in any one of Claims 8 to 10, in which the polarisation adjuster of each of the pixels of the first set further comprises a second 90 degree rotator disposed between the first linear polariser and the liquid crystal.

12. A modulator as claimed in Claim 9, in which the polarisation adjuster of each of the pixels of the first set further comprises a first +45

degree rotator disposed between the first linear polariser and the liquid crystal, the polarisation adjuster of each of the pixels of the second set further comprises a first -45 degree rotator disposed between the second linear polariser and the liquid crystal, each pixel of the first set further comprises a second -45 degree rotator disposed between the liquid crystal and the third linear polariser, and each pixel of the second set further comprises a second +45 degree rotator disposed between the liquid crystal and the fourth linear polariser.

13. A modulator as claimed in any one of Claims 1 to 7, in which the polarisation adjuster of each of the pixels of the first set comprises a third 90 degree rotator and a fifth linear polariser disposed between the third 90 degree rotator and the liquid crystal and the polarisation adjuster of each of the pixels of the second set comprises a sixth linear polariser, the polarising directions of the fifth and sixth linear polarisers being parallel.

14. A modulator as claimed in Claim 13, in which the fifth and sixth linear polarisers comprise respective portions of a first linear polarising layer.

15. A modulator as claimed in Claims 13 or 14, in which each pixel of the first set further comprises a seventh linear polariser disposed between the liquid crystal and the second substrate and each pixel of the second set comprises an eighth linear polariser disposed between the liquid crystal and the second substrate and a fourth 90 degree rotator disposed between the eighth linear polariser and the second substrate, the polarisation directions of the seventh and eighth linear polarisers being parallel.

16. A modulator as claimed in Claim 15, in which the seventh and eighth linear polarisers comprise respective portions of a second linear polarising layer.

17. A modulator as claimed in Claim 13 or 14, in which each pixel of the first set further comprises a first +quarter waveplate disposed between the liquid crystal and the second substrate and a ninth linear polariser disposed between the liquid crystal and the first +quarter waveplate and each pixel of the second set further comprises a first -quarter waveplate disposed between the liquid crystal and the second substrate and a tenth linear polariser disposed between the liquid crystal and the first -quarter waveplate, the polarisation directions of the ninth and tenth linear polarisers being parallel.

18. A modulator as claimed in Claim 17, in which the ninth and tenth linear polarisers comprise respective portions of a third linear polarising layer.

19. A modulator as claimed in any one of Claims 1 to 7, in which the polarisation adjustor of each of the pixels of the first set comprises a second +quarter waveplate and an eleventh linear polariser disposed between the second +quarter waveplate and the liquid crystal and the polarisation adjustor of each of the pixels of the second set comprises a second -quarter waveplate and a twelfth linear polariser disposed between the second -quarter waveplate and the liquid crystal, the polarisation directions of the eleventh and twelfth linear polarisers being parallel.

20. A modulator as claimed in Claim 19, in which the eleventh and twelfth linear polarisers comprise respective portions of a fourth linear polarising layer.

21. A modulator as claimed in Claim 19 or 20, in which each pixel of the first set further comprises a third -quarter waveplate disposed between the liquid crystal and the second substrate and a thirteenth linear polariser disposed between the liquid crystal and the third -quarter waveplate and each pixel of the second set further comprises a third +quarter waveplate disposed between the liquid crystal and the second substrate and a fourteenth linear polariser disposed between the liquid crystal and the third +quarter waveplate, the polarisation of the thirteenth and fourteenth linear polarisers being parallel.

22. A modulator as claimed in Claim 21, in which the thirteenth and fourteenth linear polarisers comprise respective portions of a fifth linear polarising layer.

23. A modulator as claimed in any one of Claims 10, 11, 13, 14, 19 and 20, further comprising a sixth linear polarising layer disposed adjacent the second substrate.

24. A modulator as claimed in Claim 23, in which the sixth linear polarising layer is disposed externally to the pixels.

25. A modulator as claimed in any one of Claims 8 to 12, in which each of the pixels of the first set comprises a first alignment layer disposed between the first linear polariser and the liquid crystal and having an alignment direction substantially perpendicular to the first

polarisation direction and each of the pixels of the second set comprises a second alignment layer disposed between the second linear polariser and the liquid crystal and having an alignment direction substantially perpendicular to the second polarisation direction.

26. A modulator as claimed in any one of Claims 1 to 24, in which each of the pixels comprises an alignment layer disposed between the polarisation adjuster and the liquid crystal and having a plurality of regions of different alignment directions.

27. A modulator as claimed in Claim 26, in which the alignment layer of each of the pixels has first and second regions of substantially perpendicular alignment directions.

28. A spatial light modulator comprising a liquid crystal layer, a substrate and a pixellated polarisation adjusting layer disposed between the liquid crystal layer and the substrate, the modulator comprising a plurality of pixels arranged to operate in the same mode.

29. A spatial light modulator comprising a liquid crystal layer, a substrate having residual birefringence, and a polariser disposed between the liquid crystal layer and the substrate.

30. A spatial light modulator substantially as hereinbefore described with reference to an as illustrated in Figures 5 to 20 of the accompanying drawings.

The Patent Office

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Claims searched:	1 to 30	**Date of search:**	28 November 1995

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Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.N): G2F(FSX)

Int Cl (Ed.6): G02F 1/1335

Other: ONLINE: EDOC WPI JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X,Y	GB 2155193 A	(NITTO)-see page 1 line 1 to page 2 line 29	X:29 Y:1, 28
X,Y	WO 85/02914 A1	(POLAROID)-see pages 1 to 4; claim1	X:29 Y:1, 28
Y	US 5264964	(FARIS)-see figures 5, 6, and 7	Y:1, 28

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